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(54) Fingerprint minutiae matcher.

(57) A machine or process for comparing fingerprints based on the correspondence between fingerspring minutiae.

The pattern of minutiae in an unknown or search fingerprint is rotated and translated to obtain approximate registration with the pattern of minutiae in a known on file fingerprint. Following rotation and translation, only those search and file fingerprints that exhibit a sufficient number of mating minutiae between the fingerprints are compared further.

For each pair of mating search and file minutiae, the neighboring mating minutiae are compared and an individual minutia "match score" is determined based on the degree of correspondence between the other mating pairs of minutiae within a specified neighborhood of the individual pair of mating search and file minutiae. The individual "match scores" for each of the mating minutiae are summed to yield a total score that is indicative of the correspondence between the search and the file fingerprints.

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FINGERPRINT MINUTIAE MATCHER

BACKGROUND OF THE INVENTION

A fingerprint can be characterized by the locations and angular orientations of the ridge endings and ridge bifurcations within the fingerprint which data are referred to in this specification as "minutiae". Machines for the detection and listing of fingerprint minutiae are described in a number of U.S. Patents, including Nos. 3,611,290; 3,699,419; 4,083,035; and 4,151,512.

This invention pertains to processes and machines for the automatic comparison of one fingerprint, referred to here as the "search" fingerprint with another fingerprint, referred to as the "file" fingerprint, to determine if the two prints were made by the same finger.

A minutia pattern matcher invented by Riganati and Vitols is described in U.S. Patent No. 4,135,147. The present invention is closely related to the minutia pattern matcher invented by Riganati and Vitols. U. S. Patent No. 4,135,147 describes, in some detail, the prior art and the background to which both this invention and the minutiae pattern matcher pertain.

The minutia pattern matcher of Riganati and Vitols generates a "relative information vector" ("RIV") for each minutia in the unidentified ("search") fingerprint, which RIV is a detailed description of a minutia's immediate neighborhood of nearly surrounding minutiae. The matcher compares each RIV in the search print with each RIV in the known ("file") print and generates a match score for each comparison (see Cols. 8-12 of U.S. Patent No. 4,135,147). By means of a histogram, the matcher makes a global comparison of the individual matches and generates a "final score" which indicates, quantitatively, how closely the search print compares with the file print (see Col. 12 of U. S. Patent No. 4,135,147). Because the minutia pattern matcher compares each RIV in the search print with each RIV in the file print, the process involves a significant amount of effort.

The present invention significantly reduces the effort expended in the comparison, first, by performing a preliminary comparison of search and file minutiae on a global basis in order to reject file prints which bear little resemblance to the search print (to give a "quick out") and, second, by, in effect, comparing each search RIV with only a single,

mating file RIV. The details of the present process also differ from those of the minutia pattern matcher.

SUMMARY OF THE INVENTION

This invention is a machine or process that compares or "matches" fingerprint minutia patterns. The result of this matching process is a match score which is a measure of the similarity of the two minutia patterns, with a high match score indicating a high degree of similarity. The machine of this invention is a general purpose computer, such as the IBM 7090, that has been programmed in accord with this specification.

The inputs to the machine are (1) the minutia data for the fingerprints being matched (one print is designated the search print, the other the file print), which minutia data consist of the locations (x,y) and angular orientations (θ) of the minutiae, and (2) a set of machine operating parameters. The minutia data are ordered in a θ in a lowest to highest values of θ. Tables 1(a) and 9(b) show an example of minutia data in tabular form (the format in which the computer stores and uses the data), and Figures 1A, B and C are plots of such data.

The object of the invention is to measure the similarity between two minutia patterns, such as those shown in Figures 1A and 1B. A high degree of similarity exists between the patterns in Figures 1A and 1B, as is shown in the superimposed patterns of Figure 1C where the search minutia of Figure 1A have been rotated by an angle α and translated in X an amount X_T and in Y an amount Y_T, and then superimposed on the file pattern.

One measure of similarity is the number of corresponding minutiae. To determine this number, one can think of a small box being drawn around each search minutia as shown in Figure 2A. If there is a file minutia within the box which also has the minutia angle close to the search minutia angle (say, within 25^o), then the two minutiae are said to correspond, or to be mates. Figures 2A, B and C illustrate several cases of mating, non-mating, and multiple mating minutia pairs. There are 13 corresponding or mating minutia pairs in Figure 1C. This number of mating minutiae, designated M_M, is used as a preliminary measure of similarity.

If M_M is sufficiently high, a score is computed for each search minutia based on the number of neighboring search minutiae (up to some number such as eight) that also have a mating file minutia, and on the degree of correspondence between the neighboring, mating file and search minutia. The match score for the entire fingerprint is the sum ·· the scores for each search minutia.

·· number of mating minutiae, M_M, is not greater than some spe ·reshold, the file print is considered to be unrelated to the sea and the fingerprints are not compared further.

Tab.. a listing of all the major steps in the comparison or matching pr ·. A more detailed functional description of each of these steps is given in the following sections.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B are examples of search and file minutiae respectively;

Figure 1C shows the search minutiae of Figure 1A rotated and superimposed on the file minutiae in Figure 1B;

Figures 2A, B and C show examples of mating and non-mating pairs of minutiae;

Figure 3 shows the search minutiae of Figure 1A with each minutiae numbered;

Figures 4A and 4B contain a second example of search and file minutia patterns;

Figure 5 is a two-dimensional histogram for the example in Figures 4A and 4B;

Figure 6 is a flow diagram of the logic used to compare the search and file minutiae;

Figure 7 contains an example of overlaid plots of search and file minutiae;

Figure 8 is a logic flow diagram illustrating the detailed logic for processing the NHIT list of Table 8; and

Figure 9 is a flow diagram illustrating the minutia pairing logic.

DESCRIPTION OF THE PREFERRED EMBODIMENT

1.0 PREPARATION OF SEARCH MINUTIA DATA

In a typical application of the invention, a single search fingerprint is compared against many file fingerprints. Certain computations, involving the initial search minutia data only, are done only once at the beginning of the series of comparisons.

1.1 SORT INTO ANGLE ORDER

To decrease the computation time, the search minutiae are sorted, based on their angle, in ascending order as shown in Table 1. If the minutiae are already sorted with respect to θ, this step is skipped.

1.2 FIND CLOSEST NEIGHBORS

Since the scoring for each pair of mating minutiae is dependent on the number of neighbors that also have mates, the N_N nearest neighbors for each search minutia must be defined. The number N_N is a match parameter selected by the machine operator and is typically chosen to be in the range of 6 to 12. The "nearness" measure is the sum of the absolute values of the differences in the X and Y coordinates between two minutiae. Such a measure is easily computed and results in a diamond shaped neighborhood area. Figure 3 shows the search minutiae of Figure 1A with each minutia numbered. Table 3 lists the nearest eight neighbors for some of the search minutiae. The nearest neighbors for each minutia are determined by computing the distance from each minutia to all other minutiae and selecting the N_N closest minutia as the nearest neighbors.

1.3 ROTATE SEARCH MINUTIAE FOR EACH ANGULAR POSITION

Since the X, Y, θ minutia values for the search and for the file fingerprints initially are not located with respect to a unique coordinate system, it usually is necessary to rotate one of the minutia patterns with respect to the other to properly align the matching fingerprints, as illustrated, for example, in Figure 1C. There appears to be no straightforward method of computing a best rotation based on some criteria such as

a least-squared-error fit. Accordingly, in this process, the search minutiae are rotated through a series of preselected angles and these rotated sets of minutiae are stored. In the matching process, each set of rotated search minutiae are compared with the file print and the set which gives the best match (as measured by the number of paired minutiae) is used in computing the match score for the pair of prints being compared.

In the preferred embodiment, a discrete set of rotations, N_R, spaced 5.6 degrees apart are used in the matching process. A set of ten such rotations covers a range of $\pm$ 28 degrees and normally is sufficient to allow for variations in fingerprint orientation. The number of rotations, N_R, is a match parameter specified by the operator, and can be made as large as desired in order to accommodate larger uncertainties in print orientation. Since a larger number of rotations would require more comparisons, it is desirable to use as small a value of N_R as practicable.

Functionally, the rotated X and Y minutia values are computed by the matrix equation

$$\begin{bmatrix} X_R \\ Y_R \end{bmatrix} = \begin{bmatrix} \mathrm{COS}\alpha & \mathrm{SIN}\alpha \\ \mathrm{SIN}\alpha & \mathrm{COS}\alpha \end{bmatrix} \begin{bmatrix} X_S \\ Y_S \end{bmatrix} \qquad (1)$$

where X_R,Y_R are the rotated minutia values, X_S, Y_S are the initial search minutia values, and α is the rotation angle. In order to use only integer computations and to avoid using sine and cosine functions, the following approximations are used for the sine and cosine computations:

$$\mathrm{COS}\alpha = 1 - 32/\mathrm{CDIV(N)} \qquad (2)$$

$$\mathrm{SIN}\alpha = 32/\mathrm{SDIV(N)} \qquad (3)$$

The CDIV(N) and SDIV(N) functions are represented by integer tables which have values for each N corresponding to discrete values of α. Values of CDIV(N) and SDIV(N) are computed from the inverse of the above equations and have the form

$$\mathrm{CDIV(N)} = \frac{32}{1 - \mathrm{COS}\alpha} \qquad (4)$$

$$\mathrm{SDIV(N)} = \frac{32}{\mathrm{SIN}\alpha} \qquad (5)$$

where N has values 1, 2, ... N_{RT},

α has values $(-N_{RT}+1)$ (5.6^{o}), $(-N_{RT}+3)$ (5.6^{o}), $(-N_{RT}+5)(5.6^{o})$,

... $(-N_{RT}+2N_{R}-3)(5.6^{o})$, $(-N_{RT}+2N_{RT}-1)(5.6^{o})$

and N_{RT} is the total number of rotations permissable and is an even integer.

The values of θ for each rotation can be obtained simply by adding an angle to each θ value equal to the rotation α defined above. This addition, however, is performed later in the matching process, thus avoiding the creation of an additional array of rotated values for θ.

In order to minimize the computational errors in the rotation calculations, the search minutiae are initially centered over the origin. The rotation computations then are performed for the translated data set, and the rotated minutia sets then are retranslated to the first quadrant so that all X and Y values for the minutiae are positive.

2.0 PREPARATION OF FILE MINUTIA DATA

Very little preparation of the file print minutia data is necessary or desirable since these computations need to be performed for each file fingerprint with which the search print is compared. The file data are arranged in order with respect to θ and the minimum and maximum minutia X and Y values are determined for the file print, but these calculations need be done only once for each file print for instance, at the time the file print data is added to the data base. A simple computation also can be done at the time the file print is added to the data base to determine the quantization parameters for use with the histograms described in the next section.

3.0 PRINT REGISTRATION

Print registration or orientation matching requires the determination of the best angular rotation and the X and Y offsets or translation that are necessary to superimpose the search minutia pattern upon the file minutia pattern. This task is accomplished by constructing for each of the N_R rotations of the search minutia pattern, a two dimensional histogram of the displacements in X and Y needed to overlay each search minutia with each file minutia for which the values of θ differ by less

than some threshold, which threshold is a matching parameter selected by the operator. If the computed displacements for a pair of search and file minutiae are greater than some specified threshold, this minutia pair is omitted from the histogram. An example of such a pair of minutia would be one near the top of one print and the other near the bottom of the other print. Such minutiae would not represent mating pairs. A large peak in the histogram indicates a large number of mating minutia pairs, and the coordinates of that peak give the X and Y offsets needed to give the best line up of the two minutia patterns for a particular angular rotation.

To illustrate and more precisely describe these operations, consider the example minutia patterns shown in Figures 4A and 4B, which example differs from the one shown in Figures 1-3. The search minutia pattern is one of the rotated sets of search minutia patterns. If the file minutia pattern is shifted 10 units in X and 10 units in Y (10 is added to each of the minutia X and Y values), there is almost a perfect correspondence between the search and file minutia patterns. Table 4 contains a minutia comparison matrix. This matrix lists the result of comparing each search minutia (the leftmost column of the matrix) with each file minutia (the top row of the matrix). The matrix entries show the results of the comparison. The letter A indicates that the tail angles for the two minutiae corresponding to that matrix element (e.g., search minutia, S1, and file minutia F8) differ by more than the allowed amount (30 degrees).

The two numerical entries for each pair of file and search minutia (e.g., 24, -20 for S2, F1) indicate the increments in X and Y that must be added to the file minutia data in order to superimpose that file minutia on top of the search minutia after the centers of the search and file minutia patterns have been made coincident.

The coordinates for the center of the search print are the average of the X and Y values respectively for the search minutiae. The Y coordinates for the center of the file print are the mid-points between the maximum and minimum values of X and Y respectively for the file minutiae. The center for each minutia pattern is shown by the + symbol in Figures 4A and 4B.

The coordinate values shown for each minutia in the top row and left column of the comparison matrix of Table 4 are with respect to the center of the print. Thus, to compute the translations in X and Y, ΔX and ΔY, that are required to superimpose two minutiae, such as S2 and F4, the values of the file minutia are subtracted from the values of the search minutia, as shown by the equations of Figure 4. For the S2, F4 minutia pair, these differences are 12 and 10 for X and Y, respectively, as shown in the F4 column and S2 row of the comparison matrix. The +2 term in the X translation equation of Figure 4 is necessary to allow for the non-alignment of the center of the minutia patterns (the coordinates of the center of the search minutiae are 28, 30 and for the file print center are 30-30 producing a difference in the X coordinates of 2).

The entries of the letter L indicate that the translation required for the superposition of two minutiae (e.g., S2, F5) exceeds a threshold which is half of the file minutia pattern width for X and half of the file minutia pattern height for Y. Both the X and Y translations must be less than these thresholds to avoid an L entry. The width and height of the file minutia patterns of Figure 4 are 55 and 50, respectively.

Using the numbers contained in the comparison matrix, a two dimensional histogram is constructed. Figure 5 shows such a histogram for the example of Figure 4. Each cell of the histogram corresponds to the translations in X and Y listed on the top and left edges of the histogram. The number within each cell indicates the number of minutia pairs that exist for a given X and Y translation of the search print. The histogram is constructed by first setting all cells in the histogram to zero and then incrementing (by 1) each histogram cell that corresponds to the numerical entries in the comparison matrix of Table 4. Thus, for example, the minutia pair S2, F3, with a comparison matrix entry of 24, 5 causes the contents of the (24,25; 5,4) histogram cell to be incremented by one. As can be seen by an examination of Figures 4 and 5, all of the correct or proper corresponding minutia pairs (e.g., (S1,F3), (S3,F4) etc.), cause either the (14,15; 11,10) histogram cell or an adjacent cell to be incremented.

To determine from the histogram the best X,Y translation, a search is made of the histogram cells to find the cell with the maximum value. The coordinates of the cell with the maximum value gives the translation values in X and Y which uield the maximum degree of matching. Because of the discrete nature of the process, a slight modification of the procedure is used to avoid edge or boundary problems that produce quantization

errors. In the example, there actually are eight pairs of corresponding minutiae. Only four of these pairs are counted in the (14,15; 11,10) histogram cell. The counts for the other four pairs appear in the left and top adjacent cells due to slight variations in the spacing between minutiae of the two patterns. To allow for these edge or boundary problems, the maximum count for the histogram is computed based on the sum of the counts for four adjacent cells. Thus, the maximum count for the histogram of Figure 5 is eight, and using the center of the cluster of four cells that gives this maximum, the X and Y translations that best line up the two minutia patterns are (using integer computations) 13 and 11 (assuming an initial alignment of the print centers).

The actual mechanization of this alignment procedure, while functionally the same, is somewhat different computationally from that described in the example. One difference is that a comparison matrix as such is never constructed; the computations are done for each minutia pair comparison by means of two nested DO loops, with the histogram being updated at the completion of each minutia pair computation. The desirability of having the minutiae sorted by angle is apparent from an examination of the comparison matrix of Table 4, since all of the A entries for a given row are in one or two sequential groups which include at least one end of the row. Logic is used in the DO loop computation based on these sequential angle differences to reduce the number of minutia pair computations.

Other computation differences are concerned with the manner in which the boundary problem for the histogram is handled and the construction of the histogram for the matcher where, in effect, four more or less independent computations proceed in parallel.

The minutia pattern line-up or registration process is functionally identical to a two-dimensional discrete pattern correlation process wherein one pattern is placed on top of another, the number of corresponding features are counted, a correlation matrix element is incremented, the pattern is shifted a small increment, and the corresponding features again are counted, etc.

In order to determine the best rotation angle for lining up or registering two prints, histograms as described above are constructed in sequence for each rotation angle. The rotation angle which gives the maximum histogram entry is the best rotation angle. If there is more than one maximum in the histogram (i.e., two or more cells have the same

count which is higher than all others), the coordinates for each maximum are computed and stored as well as the rotation angles. Such a condition represents two equally good pattern registrations as determined by the above registration process. The rest of the matching process is executed for each of these maximums (up to five) and a match score is computed for each. The highest resulting match score is taken as the print match score.

4.0 TEST FOR EARLY OUT

After the two prints have been registered, the maximum histogram entry, M_M^*, is a measure of how well the minutia patterns match since it is approximately the number of minutiae that are mates. (This measure is not exact because of possible double counting - one search minutia might be "paired" with more than one file minutia by the above process.) A comparison of M_M^* is made with an early out threshold, E_T. E_T is a matching parameter that is specified by the operator. The value of E_T is dependent on the type of search prints used. A typical value for latent search prints is 15. If $M_M^* < E_T$, a zero match score is assigned, and no further match computations are performed for these two prints. IF $M_M^* \geq E_T$, a more refined minutia pairing and scoring procedure is used, as described in the following sections.

5.0 MINUTIA PAIRING AND SCORING PROCEDURE

The process for minutia pairing and scoring is outlined in Figure 6. Figure 6 is a flow diagram of the pairing and scoring process. The various procedures indicated by the blocks in Figure 6 are discussed in more detail in the following subsections. The process is illustrated in Figure 7 for which the corresponding minutia data are tabulated in Table 5. Figure 7 contains an example of the overlaid plots corresponding to tabular listings of X, Y and θ minutia values and is used to illustrate the specifics of the process.

5.1 FORMATION OF INITIAL HIT LIST

The first step in the minutia pairing and scoring process is the formation of a list called the "HIT" list which is a list of the search

and file minutiae which are near enough to each other to be considered as potential mating pairs of minutiae. Table 6 is a "HIT" list for the example illustrated in Figure 7 and lists for each search minutia those file minutiae which are "close to" it. In order for a file minutia to be considered close to a search minutia, the file X, Y and θ values must satisfy the equations

$$
\begin{aligned}
|X_{Si} - X_{Fj}| &= \Delta W_{ij}, \quad \Delta X_{ij} \leq E_X \\
|Y_{Si} - Y_{Fj}| &= \Delta Y_{ij}, \quad \Delta Y_{ij} \leq E_Y \\
|\theta_{Si} - \theta_{Fj}| &= \Delta\theta_{ij}, \quad \Delta\theta_{ij} \leq E_\theta
\end{aligned}
\qquad (6)
$$

X_{Si}, X_{Fj}, Y_{Si}, Y_{Fj}, θ_{Si}, and θ_{Fj} represent the ith search and the jth file X, Y, and θ minutia values respectively, and E_X, E_Y and E_Θ are the permissable X, Y and θ pairing errors.

For minutia pairs (i,j) which satisfy this criteria, a distance or closeness measure, D_{ij}, is computed as:

$$D_{ij} = \Delta X_{ij} + \Delta Y_{ij} + \Delta\theta_{ij}/S_\theta \qquad (7)$$

where S_θ is a quantity used to scale the θ differences to the same range as the X and Y distances and depends on the units used to represent X, Y and θ. For X and Y measured in .008 inch units and θ measured in 5.6 degree units, S_θ would be 4. In addition to satisfying equations (6), in order for a file minutia to be considered close to a search minutia, the following distance relationship must also be satisfied:

$$D_{ij} \leq D_M \qquad (8)$$

where D_M is the permissable distance error. This distance measure is also shown for each of the minutia paris listed in Table 6. All file minutia which are "close" to a search minutia (up to a limit of four) are listed in the initial HIT list in ascending order of closeness as measured by D_{ij}, as shown in Table 6.

5.2 NEIGHBORHOOD HIT LIST

The rest of the minutia pairing and scoring procedure involves examining all possible search and file minutia combinations and selecting that combination which tends to maximize the match score under a closeness-of-fit scoring technique for the neighboring pairs of minutiae. To determine which neighboring search minutiae also have mating file minutiae, a list is formed for each mating search minutia, called the "NHIT" list. An example of an "NHIT" list appears in Tables 7(a)-7(e). The left-most column of this list is a list of the N closest search minutia to that search minutia (called here the neighborhood center minutia) for which the list is formed. The right-hand most column is a list of file minutia (up to two) which are close to the search minutia listed in the left-most column of the table. These neighborhood closeness and distance measures are computed in accord with equations (6), (7) and (8), although different values of E_X, E_Y, E_θ, S_θ, and D_M (i.e., E_{XN}, E_{YN}, $E_{\theta N}$, $S_{\theta N}$, and D_M) can be specified. That is, the tolerances and scaling factors can be different for the HIT and NHIT lists. In Table 7(a), the NHIT list for the search and file pair of minutia (S4,F4) is shown together with the nearness or closeness measure for the four closest neighbors to minutia S4 (i.e., S3, S2, S8, S1). This list only includes the two closest file minutiae for a given search minutia. Duplicate file minutiae are eliminated from the list according to a set of logic which first maximizes the number of search minutiae having a mating file minutia, and then minimizes the distance or nearness measure when two pairs of minutiae are considered at a time.

The operation of the logic is illustrated by means of the example NHIT list of Table 8 (the minutiae of the example are not related to those of the example in Table 5). The first minutia combination to be considered by the logic is the S1,F2 combination listed in the first row. However, an examination of the second row shows that F2 appears in this row also, and with a smaller distance than in row one. If minutia F2 is paired with S2 because of the smaller distance, then there is no minutia to pair with S1. In order to minimize the number of pairings, the selection is made as shown in the final pairing column of the list. The detailed logic for processing the NHIT list is shown in the folow chart of Figure 8. In Figure 8:

NB = the number of neighbors for each search minutia
NHIT(I,1) = closest file minutia to the I search minutia in the NHIT list
NHIT(I,2) = distance measure between the I search minutia in the NHIT list and the NHIT (I,1) file minutia
NHIT(i,3) = next closest file minutia to the I search minutia in the NHIT list
NHIT(I,4) = distance measure between the I search minutia in the NHIT list and the NHIT(I,3) file minutia.

Following the logic of Figure 8 and working in a top-to-bottom fashion through the list to eliminate duplicate file minutiae and then selecting the pairing giving the smallest distance measure results in the pairing shown in the "final pairing" column of the list. This logic is not sufficiently complex to always produce an optimum solution since if the file entry for row three would have been (F7,2) instead of (F8,2), the final pairing for the first three rows would have been (F2,5), - , (F7,2) which is not as good as the selection -, (F2,2), (F7,2) for which the combined distance is 4 as compared to 7 for the less complex procedure. The simpler lo[illegible], however, is used in order to improve the matching speed since situati[illegible] requiring the more complex logic are rare.

Once a NHIT list has been edited to eliminate duplicate file minutiae and the resulting, best search-file neighborhood minutia pairings have been determined (according to the above rules), the variance in the fit of the neighboring minutiae is computed. A combined variance over X, Y and θ is computed as:

$$\sigma^2 = \frac{1}{3}\left[\sigma_x^2 + \sigma_y^2 + \sigma_\theta^2/S_\theta\right] \qquad (9)$$

whereas:

$$\sigma_X{}^2 = E\left[(\Delta X - M_{\Delta X})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta X_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta X_j\right]^2$$

$$\sigma_Y{}^2 = E\left[(\Delta Y - M_{\Delta Y})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta Y_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta Y_j\right]^2 \quad (10)$$

$$\sigma_\theta{}^2 = E\left[(\Delta\theta - M_{\Delta\theta})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta\theta_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta\theta_j\right]^2$$

S_θ is a quantity used to scale the σ_θ^2 values to the same range as σ_X^2 and σ_Y^2. ΔX_u, ΔY_j, $\Delta\theta_j$ are the X, Y and θ differences between neighboring search and file minutiae, and N_M is the number of matching neighbors. Again S_θ is a function of the units used to measure X, Y and θ. For X and Y measured in units of 0.008 inches and θ in units 5.6^0, S_θ is in the range of 16-32.

In order to use integer arithmetic, equations (10) are computed using a different scale factor S_σ to scale the computed σ^2 values to appropriate integer values. The value of S_σ depends on the scoring table used and for the scoring table of Table 9, $S_\sigma = 4$. In FORTRAN notation, the equation for determining σ_X^2, equation (10), has the form:

```
IVX  =  ((MXIS - (MXI*MXI)/NMM)*IVARF/NMM
```

where: (11)

IVX $= \sigma^2_X$

MXIS $= \sum_{J=1}^{N_M}\Delta X_j^2$

MXI $= \sum_{J=1}^{N_M}\Delta X_j$

NMM $= N_M$

IVARF $= S_\sigma$

Tables 7(b) and 7 (d) show the variance computatic... for the (S4,F4) and (S4,F2) minutia pairs respectively. In these computations, $S_\sigma = 4$ and $S_\theta = 22.5$. The integer scaled values of σ^2 are indicated by σ_S^2.

Having computed t... ...e in the neighborhood fit of minutia, the individual minutia ... ...ermined from a two-dimensional scorin... table. An examp... ...ing table is shown in Table 7(... ...e dimension of the table ... ...e number of matching neighbors, a... ther is σ_S^2, the combined, s... ...riance of the fit. The ... l minutia score for the (S4,F4... ...ia pair of 0 because σ_S is greater than 14, the largest σ_S^2 entry of the table, while the individual minutia score for the S4,F2 minutia pair is 60 (the fourth row and fourth column entry of Table 7(e)). A careful examination of the minutia patterns of Table 5 shows that the (S4,F2) pairing gives a much better fit for the neighboring minutiae as the σ_S^2 computation for this pairing indicates.

Table 9 is the scoring table used in the preferred embodiment. The table is treated in the computer program as a one-dimensional table for purposes of speed and the indices to the table are computed using the specified minimum and maximum values for N_M and σ_S^2. This procedure, in effect, specifies a score for all of N_M, σ_S^2 space but it does not require an infinite table of scoring values. Thus, using FORTRAN type notation,

$$\begin{aligned}
&\text{If } N_M > N_{MX},\ N_M = N_{MX} \\
&\text{If } N_M < N_{MN},\ S_M = 0 \\
&\text{If } \sigma_S^2 > \sigma_{SX}^2,\ S_M = 0 \\
&\text{If } \sigma_X^2 < \sigma_{SN}^2,\ \sigma_S^2 = \sigma_{SN}^2
\end{aligned} \qquad (12)$$

where N_{MX}, N_{MN}, $\sigma_{SX}{}^2$, and $\sigma_{SN}{}^2$ are the maximum and minimum allowed values of N_M and $\sigma_S{}^2$ respectively. In Table 9 $N_{MX} = 12$, $N_{MN} = 4$, $\sigma^2_{SX}, = 30$, and $\sigma_{SN}{}^2 = 1$. Table 9 was developed by intutitive and empirical means so as to give a high score when the search and file fingerprints are similar, and a low score when they are dissimilar.

When the score S_{Mij}, for a given search minutia-file minutia pair (as listed in the initial HIT list), has been determined from its relationship to its closest neighbors, this score is entered in the initial HIT list in place of the distance measure initially computed for this minutia pair. This procedure is repeated until scores have been determined for all minutia pairs defined by the initial HIT list. Table 10(a) is the HIT list for Table 6 with the distance measure replaced by the individual minutia scores. In order to avoid considerable hand computations to provide this example, all of the S_{Mij} entries except for the S_{M44} entries are rough approximations, but are sufficiently representative to illustrate the essential features of the process.

5.3 DETERMINATION OF FINAL HIT LIST AND INDIVIDUAL MINUTIA SCORE

When all of the score entries have been made in the initial HIT list, the file minutia entries for each row are re-ordered to be in decending order based on the score entries, and only the first two entries are retained in the HIT list. The right-most column of the example HIT list of Table 10(a) shows the effect of this or-ordering and truncation.

Using the truncated, score-ordered HIT list, multiple file minutiae are eliminated by selecting that pairing which maximizes the total score when minutia pairings are considered two at a time. The selection process for the example of Table 10 is straightforward- in the right-most column of Table 10(a), the file minutia with the lowest score is always eliminated if multiple entires exist. Those file minutiae to be eliminated are indicated by a star (*) in this table.

A situation not quite so straightforward is shown in Table 11. If the lowest scoring file minutiae are eliminated, there is no mating file minutia for search minutiae S2, S4, S7, and S8. The selection logic considers the pairing for two search minutiae at a time and is such that the combined score for the two minutia pairing is maximized. Figure 9

contains a flow chart of the process. In Figure 9:

NS = number of search minutia
HIT(i,1) = file minutia number with largest score on ith row of HIT array
HIT(i,2) = score for file minutia of H(i,1)
HIT(i,3) = file minutia number with second highest score on ith row of HIT array
HIT(i,4) = score for file minutia of H(i,3)

A HIT entry of 999 indicates an empty cell or no minutia pairing.

The result of the application of the process shown in Figure 9 to the example of Table 11 is shown in the right-most column of Table 11. The logic is not sufficiently complex to truly maximize the score over all possible pairing combinations. In the example of Table 11, the score would be five points higher if file minutia F9 were paired with search minutia S3 instead of S4 as shown. Such situations requiring more complex logic, however, seem to be very rare, and hence the added logic complexity that would be needed to handle such situations is not included as part of the match procedure.

6.0 FINAL MATCH SCORE

The final match score for the entire print is simply the sum of the match scores for each individual search minutia, as determined from the final HIT list. This is illustrated at the bottom part of Table 10(b).

The invention is mechanized by means of a FORTRAN routine run on any suitable computer system such as the IBM 7090. Appendix I contains a FORTRAN listing of the computer program. Appendix II contains a list of the more significant program variables.

Although the invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

MINUTIA NO.	MINUTIA COORDINATES		
NO.	X	Y	θ
1	103	13	2
2	18	21	8
3	51	93	40
4	8	29	45
5	30	40	90
6	90	79	130
7	117	43	135
8	116	87	135
9	90	50	160
10	55	30	165
11	120	24	172
12	85	21	174
13	72	98	182
14	101	111	184
15	47	16	187
16	42	99	220
17	23	72	250
18	60	70	295
19	43	52	305
20	70	80	318

a) SEARCH MINUTIA

MINUTIA NO.	MINUTIA COORDINATES		
NO.	X	Y	θ
1	41	118	40
2	34	93	62
3	20	18	67
4	34	36	118
5	75	95	148
6	112	72	170
7	88	69	175
8	78	48	181
9	94	40	185
10	61	36	193
11	73	129	212
12	23	95	250
13	18	63	275
14	33	74	284
15	46	54	320
16	95	91	331
17	58	89	344

b) FILE MINUTIA

TABLE 1

LIST OF BASIC STEPS IN PROCESS

1.0 PREPARE SEARCH MINUTIA DATA
   1.1 SORT INTO ANGLE ORDER
   1.2 FIND CLOSEST NEIGHBORS
   1.3 ROTATE SEARCH MINUTIA FOR EACH ANGULAR POSITION

2.0 PREPARE FILE MINUTIA DATA
   2.1 SORT INTO ANGLE ORDER
   2.2 FIND MIN AND MAX X AND Y VALUES
   2.3 COMPUTE QUANTIZATION PARAMETERS

3.0 PRINT REGISTRATION (FIND BEST ANGLE ORIENTATION AND X,Y OFFSETS FOR LINING UP SEARCH AND FILE MINUTIA PATTERNS)
   3.1 FOR EACH ANGULAR ROTATION BUILD A TWO DIMENSIONAL HISTOGRAM OF X,Y TRANSLATIONS TO OVERLAY ALL POSSIBLE MINUTIA PAIRS
   3.2 DETERMINE X,Y TRANSLATIONS CORRESPONDING TO MAXIMUM OF HISTOGRAM
   3.3 DETERMINE ROTATION ANGLE FOR MAXIMUM OF ALL HISTOGRAMS
   3.4 DETERMINE MAXIMUM VALUE OF ALL HISTOGRAMS, M^*_m

4.0 TEST FOR EARLY OUT
   4.1 COMPARE M^*_m WITH THRESHOLD, E_T
   4.2 IF $M^*_m < E_T$, ASSIGN ZERO MATCH SCORE, EXIT
   4.3 IF $M^*_m > E_T$, PROCEED

5.0 "ROTATE, TRANSLATE" SEARCH MINUTIA TO BEST MATCH POSITION. DETERMINE WHICH SEARCH MINUTIA MATE WITH WHICH FILE MINUTIA

6.0 FOR EACH SEARCH MINUTIA WHICH HAS A MATING FILE MINUTIA, TRANSLATE SEARCH MINUTIA SO THESE MATING MINUTIA COINCIDE. COUNT HOW MANY OF N_c CLOSEST NEIGHBORING SEARCH MINUTIA ALSO HAVE A MATING FILE MINUTIA, N_m. COMPUTE THE INDIVIDUAL MINUTIA SCORE, I_{si}, AS $I_{si} = N_{Mi}^2$

   6.1 FORM INITIAL "HIT" LIST
   6.2 FORM NEIGHBORHOOD HIT ("NHIT") LIST
   6.3 DETERMINE FINAL HIT LIST AND INDIVIDUAL MINUTIA SCORE

7.0 COMPUTE TOTAL FINAL MATCH SCORE S_M, AS $S_M = \sum_{i=1}^{N_s} I_{si}$

TABLE 2

MINUTIA NO.	8 NEAREST NEIGHBORS
1	11, 12, 7, 9, 15, 10, 6, 8
2	4, 5, 15, 10, 17, 19, 18, 12
3	16, 13, 20, 18, 6, 19, 17, 14
4	2, 5, 15, 10, 17, 19, 18, 12
5	4, 2, 17, 19, 10, 15, 18, 9
6	20, 13, 8, 14, 9, 18, 3, 7
⋮	

TABLE 3

	F1 (−5,25)	F2 (20,10)	F3 (−5,0)	F4 (3,−8)	F5 (−20,−10)	F6 (−5,−15)	F7 (−25,5)	F8 (−28,5)	F9 (−20,−25)	F10 (5,−25)	F11 (27,−10)
S1 (7, 10)	14,−15	−11,0	14,10	6,16	L	14,25	A	A	A	A	A
S2 (17,5)	24,−20	−1,−5	24,6	12,10	L	24,20	A	A	A	A	A
S3 (−8,0)	−5,−25	−26,−10	−1,0	−9,+6	14,10	−1,15	A	A	A	A	A
S4 (7,−5)	L	−11,−16	14,−5	6,0	L	14,10	A	A	A	A	A
S5 (−16,5)	A	A	A	A	A	A	9,0	12,10	A	A	A
S6 (−13,18)	A	A	A	A	A	A	14,13	17,23	A	A	A
S7 (−8,−13)	A	A	A	A	A	A	A	A	14,12	−11,12	L
S8 (17,−16)	A	A	A	A	A	A	A	A	L	14,10	−8,−3

TABLE 4

SEARCH MINUTIA

NO.	X	Y	θ
1	8	8	25
2	14	21	27
3	10	20	30
4	6	17	32
5	36	10	150
6	31	8	155
7	26	14	160
8	14	14	235
9	28	22	325
10	32	22	330
11	39	22	340

FILE MINUTIA

NO.	X	Y	θ
1	18	23	25
2	10	19	25
3	14	22	28
4	5	14	30
5	8	9	30
6	12	10	32
7	28	16	150
8	24	12	160
9	39	12	160
10	35	9	162
11	27	8	170
12	12	15	210
13	18	15	230
14	32	24	320
15	36	23	332
16	25	22	342

TABLE 5

HIT LIST

SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE
S1	(F5,2), (F6,8), (F4,10)
S2	(F3,1), (F1,6), (F2,6)
S3	(F2,2), (F3,6), (F4,11), (F1,12)
S4	(F4,4), (F2,8), (F5,10), (F3,14)
S5	(F10,3), (F9,7)
S6	(F11,6), (F10,6)
S7	(F8,4), (F7,6), (F11,9)
S8	(F13,6), (F12,8)
S9	(F16,6), (F14,7), (F15,10)
S10	(F14,4), (F15,5), (F16,9)
S11	(F15,5), (F14,13)

TABLE 6

INITIAL NHIT LIST, (S4,F4) PAIRING

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE
S3	(F2,2), (F3,9)
S2	(F2,5), (F3,6)
S8	(F12,7), (F13,9)
S1	(F5,6), (F6,11)

(a)

FINAL NHIT LIST, (S4,F4) PAIRING

SEARCH MINUTIA	FILE MINUTIA	ΔX	ΔY	$\Delta\theta$
S3	F2	1	2	−5
S2	F3	1	4	1
S8	F12	−1	4	−25
S1	F5	1	4	5
	σ^2	0.75	0.75	133

$$\sigma_S^2 = 4(0.75) + 4(0.75) + 4(133)/22.5$$
$$= 30$$
$$S_{M44} = 0$$

(b)

INITIAL NHIT LIST, (S4,F2) PAIRING

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE
S3	(F23,1), (F1,6)
S2	(F1,0), (F3,5)
S8	(F13,2), (F12,10)
S1	(F6,2), (F5,6)

(c)

FINAL NHIT LIST, (S4,F2) PAIRING

SEARCH MINUTIA	FILE MINUTIA	ΔX	ΔY	$\Delta\theta$
S3	F3	0	0	−2
S2	F1	0	0	−2
S8	F13	0	−1	−5
S1	F6	0	0	7
	σ^2	0	0.19	20

$$\sigma_S^2 = 4(0) + 4(0.19) + 4(20)/22.5$$
$$= 4$$
$$S_{M42} = 60$$

(d)

EXAMPLE SCORING TABLE

$N \backslash \sigma_s^2$	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	20	10	5	1	0	0	0	0	0	0	0	0	0	0	0
3	40	20	10	5	3	1	0	0	0	0	0	0	0	0	0
4	150	120	100	80	60	40	20	10	5	3	1	0	0	0	0
5	200	150	120	100	80	60	40	20	10	5	3	1	0	0	0
6	200	200	200	150	120	100	80	60	40	20	10	5	3	1	0

(e)

TABLE 7(a)–7(e)

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE	FINAL PAIRING
S1	(F2,5) –	(F2,5)
S2	(F2,2), (F7,5)	(F7,5)
S3	(F8,2) –	(F8,2)
S4	(F8,4), (F9,6)	(F9,6)
S5	(F10,3), (F11,5)	(F10,3)
S6	(F12,3), (F14,5)	F(14,5)
S7	(F14,7) –	–
S8	F(12,1) –	F(12,1)

TABLE 8

SCORING TABLE

NM	4	5	6	7	8	9	10	11	12
1	50	100	120	150	170	200	220	250	250
2	30	60	100	120	150	180	200	220	250
3	20	40	70	110	140	150	180	210	240
4	10	20	60	100	120	140	160	200	220
5	8	16	40	70	100	110	150	190	200
6	5	10	20	40	80	100	130	170	200
7	3	8	16	32	64	90	110	160	180
8	2	6	12	24	48	80	100	150	170
9	1	5	10	20	40	70	100	140	160
10	0	3	6	12	24	50	90	130	150
11	0	2	5	10	20	40	80	120	150
12	0	1	5	10	20	40	80	110	140
13	0	0	4	8	16	32	64	100	120
14	0	0	3	6	12	24	48	100	120
15	0	0	2	4	8	16	32	70	100
16	0	0	1	3	6	12	24	50	90
17	0	0	0	2	4	8	16	40	80
18	0	0	0	1	3	6	12	30	70
19	0	0	0	0	2	4	8	20	60
20	0	0	0	0	1	3	6	10	40
21	0	0	0	0	0	2	4	8	30
22	0	0	0	0	0	1	3	6	20
23	0	0	0	0	0	0	2	4	10
24	0	0	0	0	0	0	1	3	8
25	0	0	0	0	0	0	0	2	6
26	0	0	0	0	0	0	0	1	4
27	0	0	0	0	0	0	0	0	3
28	0	0	0	0	0	0	0	0	2
29	0	0	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	0

TABLE 9

SEARCH MINUTIA	[illegible]ESPONDING FILE MINUTIA, [illegible]DUAL MINUTIA SCORES	CORRESPONDING FILE MINUTIA AFTER SCORE ORDERING AND TRUNCATION
S1	[illegible] (F4,0)	(F6,100), (F5,3)
S2	[illegible] (F2,1)	(F1,80), (F3,10)*
S3	[illegible],3), (F3,100), (F4,0), (F1,0)	(F3,100), (F2,3)*
S4	(F4,0), (F2,60), (F5,0), (F3,0)	(F2,60) (F4,0)
S5	(F10,10), (F9,20)	(F9,20) (F10,10)*
S6	(F11,20), (F10,80)	(F10,80), (F11,20)
S7	(F8,3), (F7,60) (F11,0)	(F7,60), (F8,3)
S8	(F13,100), (F12,3)	(F13,100), (F12,3)
S9	(F16,3), (F14,40), (F15,0)	(F14,40) (F16,3)
S10	(F14,5), (F15,60), (F16,0)	(F15,60), (F14,5)*
S11	(F15,3), (F14,10)	(F14,10)*, (F15,3)*

* ELIMINATED MINUTIA

(a) INTERMEDIATE HIT LIST

SEARCH MINUTIA	SELECTED FILE MINUTIA AND SCORE
S1	(F6,100)
S2	(F1,80)
S3	(F3,100)
S4	(F2,60)
S5	(F9,20)
S6	(F10,80)
S7	(F7,60)
S8	(F13,100)
S9	(F14,40)
S10	(F15,60)
S11	

MATCH SCORE = 100 + 80 + 100 + 60 + 20 + 80 + 60 + 100 + 40 + 60
= 700

(b) FINAL HIT LIST

TABLE 10

SEARCH MINUTIA	CORRESPONDING FILE MINUTIA AFTER SCORE ORDERING AND TRUNCATION	FINAL PAIRING AND SCORE
S1	(F3,40)*, (F7,35)	(F7,35)
S2	(F3,20)	(F3,20)
S3	(F9,20)*, (F11,10)*	–
S4	(F9,15)	(F9,15)
S5	(F11,50)	(F11,50)
S6	(F15,60), F(18,30)	(F15,60)
S7	(F15,10)*	–
S8	(F15,5)*	–
S9	(F21,30), (F23,15)	(F21,30)
S10	(F21,25)*, (F26,20)	(F26,20)
S11	(F31,30)*, (F32,20)	(F32,20)
S12	(F31,20), (F33,5)	(F31,20)

* ELIMINATED MINUTIA

TABLE II

APPENDIX I

ECLIPSE FORTRAN 5, VERSION 4.00

```
      SUBROUTINE MATCHP
      OVERLAY OVMAT
C
C     R&D MATCH PROGRAM (MATCHP); CALLS ASORT     DATA GENERAL   11/78
C
      PARAMETER ID1=204, ID4=204, ID3=204, ID5=20, ID6=12
      COMPILER STATIC
      COMMON/ARRAY/ F,COUNT,SCORET,IXMIN,IXMAX,IYMIN,IYMAX
      COMMON /PLOTAG/ PA,IJS,XOFS,YOFS,IPAAR,PAA,AVX,AVY
      COMMON /ARGS/ LATID,ISCDA,NP,P,IFCDA,NF,ISCOR,IFLAG,PCN
      COMMON /MATGP/ IPAR
      INTEGER P(3*ID4),COUNT(2500),F(3*ID3),PA(ID5*ID4),NAR(ID6*ID4)
     * ,SUMX,SUMY,AVX,AVY,SDIV(32),CDIV(32),NFRS(33),SCORET(16,10)
     * ,RIV(23),NPOS(5),VMAX(5),HIT(ID4),PAA(ID4),S(ID5),SS(ID5),NHIT(ID4)
     * ,NP,NF,ISCOR,ISCDA(20),IFCDA(16),IPAR(256),ISCTVR(500)
     * ,XOF,YOF,DPX,DPY,PX,PY,PXS,PYS,PCN(9),LATID(7)
     * ,DELTH,DELX,DX,ERAA,ERAM,DDX,XOFS,YOFS,PXLX,PYLY,ISTAB(512)
     * ,ASFP,ERAB,ASFN,ASFS
      EQUIVALENCE (ISTAB(21),ISCTVR(1)), (COUNT(750),HIT(1))
     * , (COUNT(630),NHIT(1)), (S(1),PA(1)), (COUNT(1),SS(1))
     * , (IPAR(26),IEOT), (IPAR(28),MXVAL), (IPAR(29),NAT)
     * , (IPAR(30),ERAA), (IPAR(31),ERAM), (IPAR(32),DELX), (IPAR(33),DX)
     * , (IPAR(34),NXMAX), (IPAR(35),NYMAX), (IPAR(36),IETP), (IPAR(37),IETPN)
     * , (IPAR(38),DDX), (IPAR(44),IOFLAG), (IPAR(61),ASFP), (IPAR(62),ERAB)
     * , (IPAR(63),ASFN), (IPAR(64),ASFS), (IPAR(135),JSMIN), (IPAR(136),IVARF)
     * , (IPAR(137),IVARMX), (IPAR(138),JSXMX), (IPAR(139),IVARMN)
C
      DATA SDIV/-32,-32,-33,-34,-35,-37,-40,-43,-48,-54,-62,-75,-95,
     * -132,-218,-652,652,218,132,95,75,62,54,48,43,40,37,35,34,33,32,32/
      DATA CDIV/34,38,42,48,56,66,79,97,124,163,225,333,547,1069,2957,24556,
     * 26556,2957,1068,547,333,225,163,124,97,79,66,56,48,42,38,34/
C
C**   PREPARE LATENT DATA
C
      DELTH = 4
      IF(NAT .GT. 32) NAT = 32
      NPK = NP+NP+4
      IF(NAT*NPK .GT. ID5*ID4) NAT = ID5*ID4/NPK
      IF (IFLAG.EQ.1) GO TO 65
C
C     OPEN AND READ FILE CONTAINING SCORING TABLE DATA
C
```

```
      OPEN 0,"RAOSTR",ERR=R030,ATT="C",LEN=512,REC=2
      CALL RDBLK(0,0,ISTAR,2,IER)
      CLOSE 0
      GO TO R030
R020  TYPE'<CR>*MATCHP* RAOSTR FILE DOES NOT EXIST'
      ISCOR = 0
      RETURN
R030  CONTINUE
      NRIV = MXNRL
      IF(NRIV .GE. NP) NRIV = NP-1
C
C      SORT INTO ANGLE ORDER
C
      IRA = ERAA + DELTH * NAT/2
      CALL ASORT(IRA,NP,MPT,P)
C
C      COMPUTE AVERAGE X AND Y
C
      NP3= NP*3
      NPCD = NP3
      SUMX = 0
      SUMY = 0
      DO 15 I = 1,NP3,3
      SUMX = SUMX + S(I)
   15 SUMY = SUMY + S(I+1)
      AVX = SUMX/NP
      AVY = SUMY/NP
C
C      CENTER LATENT AROUND ORIGIN
C
      DO 25 I = 1,NPCD,3
      SS(I) = S(I) - AVX
      SS(I+1) = S(I+1) - AVY
   25 SS(I+2) = S(I+2)
```

```
C
C       FIND CLOSEST NEIGHBORS
C
        NHIVS = NRIV+1
        NN = NP * 3
        IT=0
        DO 800 I = 1,NN,3
        DO 380 L = 1,NRIVS
        NBRS(L) = 0
  380   RIV(L) = 32767
        PX = SS(I)
        PY = SS(I+1)
```

```
          DO 750 J = 1,NN,3
          IDX = IABS(PX-SS(J))
          IDY = IABS(PY-SS(J+1))
          IR = IDX + IDY
          IF(IR .GT. IPAR(19)) GO TO 750
          IF (IR.GT.RIV(1)) GO TO 750
          DO 620 K = 2,NRIVS
          IF (IR.GT.RIV(K)) GO TO 650
          RIV(K-1) = RIV(K)
    620   NBRS(K-1) = NBRS(K)
          K = NRIVS+ 1
    650   RIV(K-1) = IR
          NBRS(K-1) = J/3 +1
    750   CONTINUE
          IEND = NRIV
    760   ITMP = 0
          DO 770 L=2,IEND
          IF(NBRS(  L).GT.NBRS(  L-1)) GO TO 770
          ITMP = NBRS(L)
          NBRS(  L) = NBRS(  L-1)
          NBRS(  L-1) = ITMP
    770   CONTINUE
          IF (ITMP.EQ.0) GO TO 799
          IEND = IEND - 1
          IF (IEND.GT.1) GO TO 760
    799   DO 780 L=1,NRIV
          IT = IT + 1
    780   NBR(IT) = NBRS(L)
    800   CONTINUE
    C
    C      ROTATE LATENT FOR EACH ANGULAR POSITION
```

```
C
      NP2 = NP+NP
      NP2CD = NP2
      JA = (32-NAT)/2 +1
      JB = (32+NAT)/2
      KM = -1
      DO 30 L =1,NPCD,3
      KM = KM + 2
      PX  = SS(L)
      PXS = 32*PX
      PY  = SS(L+1)
      PYS = 32*PY
      KK = KM
      DO 40 N=JA,JB
      PA(KK) =  PX -(PXS/CDIV(N))-(PYS/SDIV(N))
```

```
      PA(KK+1) =  (PXS/SDIV(N)) + PY - (PYS/CDIV(N))
   40 KK = KK+NP2CD
30    CONTINUE
      KKX = KK
      JF = -SS(3)
      IF(JF .LT. 0) JF = 0
      LAMIN = JF+(NAT/2)*DELTH - DELTH/2
      K = 0
      DO 90 I = 1,NP
      K = K+3
   90 PAA(I) = SS(K) + JF
      IFLAG = 1
65    CONTINUE
C
C**  PREPARE FILE DATA
C
      NF3 = NF*3
C
C      COMPUTE QUANTIZATION PARAMETERS
C
      NX = MIN0((IXMAX-IXMIN)/DELX,NXMAX)
      IF(NX.EQ.0) NX=1
```

```
      NY = MINU((IYMAX-IYMIN)/DELX,NYMAX)
      IF(NY.EQ.0) NY=1
      ICXF = (IXMAX+IXMIN)/2
      ICYF = (IYMAX+IYMIN)/2
      JFXMIN = ICXF - DELX*NX/2
      JFYMIN = ICYF - DELX*NY/2
      NX1 = NX+2
      NY1 = NY+2
      NXT1 = NX1*NY1
      LX = NX*DELX/2
      LY = NY*DELX/2
      NP8 = 8*NP
      N84 = NRIV*4
C
C  START OF BASIC MATCH ALGORITHM
C
C  FIRST, FIND THE BEST X,Y OFFSETS AND ANGLE ORIENTATIONS FOR
C      CENTERING THE LATENT PRINT OVER THE FILE PRINT
C
C      COMPUTE SEARCH POSITION LIMITS
C
      DO 3 I = 1,NXT1
    3 COUNT(I) = 0
      IANS = 2
```

```
      MMAX = 0
      II = -1-NP2CD
      IANGM = -DELTH
C
C      COUNT HITS FOR EACH ANGULAR POSITION
C
      DO 500 NANGLE = 1,NAT
      IANGM = IANGM + DELTH
      NJ = 1
      II = II + NP2CD
      IABIAS = -256-LAMIN+IANGM
      DO 300 IBA = 1,2
      IABIAS = IABIAS + 256
      IJ = II
      DO 300 I = 1,NP
      IJ = IJ + 2
      PX = PA(IJ) + ICXF
      PY = PA(IJ+1) + ICYF
      PXLX = PX - LX
      PYLY = PY - LY
      IANG = PAA(I) + IABIAS
      N = NJ
      DO 275 J = N,NF3,3
      IF (IABS(F(J+2) -IANG).GT.ERAA) GO TO 260
      IF(IABS(F(J)-PX) .GE. LX) GO TO 275
      IF(IABS(F(J+1)-PY) .GE. LY) GO TO 275
      KST = ((F(J)-PXLX)/DELX)*NY) + (F(J+1)-PYLY)/DELX + 1
      COUNT(KST) = COUNT(KST) + 1
```

```
      COUNT(KST+NY1) = COUNT(KST+NY1) + 1
      KST = KST + 1
      COUNT(KST) = COUNT(KST) + 1
      COUNT(KST+NY1) = COUNT(KST+NY1) + 1
      GO TO 275
  260 IF (F(J+2).GT.IANG)GO TO 300
      NJ = J
  275 CONTINUE
  300 CONTINUE
C
C      FIND COORDINATES OF MAXIMUM HIT COUNT
C
      DO 400 I = 1,NXT1
      NSS = COUNT(I)
      COUNT(I) = 0
      IF (NSS.LT.IANS) GO TO 400
      IF (NSS.EQ.IANS) GO TO 399
      MMAX=1
```

```
      IANS = NSS
      NPOS(MMAX) = I
      NMAX(MMAX) = NANGLE
      GO TO 400
399   MMAX = MMAX + 1
      IF (MMAX.GT.5) MMAX = 5
      NPOS(MMAX) = I
      NMAX(MMAX) = NANGLE
400   CONTINUE
500   CONTINUE
C
C  SECOND, MOVE THE LATENT PRINT AND FIND WHICH OF THE LATENT
C       MINUTIAE MATCH AND RECORD THIS IN THE HIT ARRAY.
C
      ISCORS = 0
      IF(IANS .LT. IEOT) GO TO 992
      DO 990 JZ = 1,MMAX
C
C       FIND THE POSITION OFFSETS
C
      IN = NPOS(JZ)/NY1
      JN = NPOS(JZ) - NY1*IN - 1
```

```
      IF (JN.GT.0) GO TO 601
      JN = NY
      IN = IN - 1
  601 CONTINUE
      NMAZ = NMAX(JZ)
      IJ = NP2CO*(NMAZ-1)
      XOF = IN * DELX + JFXMIN
      YOF = JN * DELX + JFYMIN
      DO 122 I = 1,NP8
  122 HIT(I) = 9999
      NJ = 1
      NANG = (NMAZ-1)*DELTH
      IABIAS = -256 - LAMIN + NANG
      DO 290 IBA = 1,2
      IABIAS = IABIAS + 256
      DO 290 I = 1,NP
      IH = 8*I-7
  278 K = IJ + I + I -1
C
C       TRANSLATE LATENT TO NEW POSITION
C
      PX = PA(K) + XOF
      PY = PA(K+1) + YOF
      IANG = PAA(I) + IABIAS
```

```
      N = NJ
      IF(N.GE. NF3) GO TO 292
C
C      IDENTIFY HITS
C
      DO 280 J = N,NF3,3
      IEA = IABS(F(J+2) - IANG)
      IF(IEA .GT. ERAM) GO TO 279
      IEX = IABS(F(J) - PX)
      IF(IEX .GT. DX) GO TO 280
      IEY = IABS(F(J+1) - PY)
      IF(IEY .GT. DX) GO TO 280
      IET = IEA/ASFP + IEX + IEY
      IF(IET .GT. IETP) GO TO 280
      JH = 6
      IF(HIT(IH+JH+1) .LE. IET) GO TO 2786
      HIT(IH+JH+1) = IET
      HIT(IH+JH) = J/3 + 1
 2783 JH = JH-2
      IF(JH .LT. 0) GO TO 2786
      IF(HIT(IH+JH+3) .GE. HIT(IH+JH+1)) GO TO 2786
      ITJ = HIT(IH+JH)
```

```
      IT2 = HIT(IH+JH+1)
      HIT(IH+JH) = HIT(IH+JH+2)
      HIT(IH+JH+1) = HIT(IH+JH+3)
      HIT(IH+JH+2) = IT1
      HIT(IH+JH+3) = IT2
      GO TO 2783
 2786 CONTINUE
      GO TO 280
  279 IF (F(J+2).GT.IANG) GO TO 290
      NJ = J
  280 CONTINUE
  290 CONTINUE
  292 CONTINUE
C
C THIRD, FOR EACH LATENT MINUTIAE WHICH IS A HIT, MOVE THE LATENT
C      PRINT SO THAT THE MATCHING MINUTIAE COINCIDE AND THEN TEST TO
C      SEE HOW MANY OF THE CLOSEST LATENT NEIGHBORS ARE ALSO A HIT.
C
      NBRI = -NRIV
      DO 898 LM = 1,NP
      NBRI = NBRI + NRIV
      DO 895 LM1 = 1,4
      IS = 8*(LM-1) + 2*(LM1-1) + 1
      IF(HIT(IS) .EQ. 9999) GO TO 898
```

```
      JFM = HIT(IS)
      JJ = (HIT(IS)-1)*3+1
      KK = IJ+LM+LM-1
C
C     COMPUTE OFFSETS TO OVERLAY LATENT AND FILE MINUTIAE
C
      DPX = F(JJ) - PA(KK)
      DPY = F(JJ+1) - PA(KK+1)
      NJ = 1
      DO 810 LL = 1,NHA
  810 NHIT(LL) = 0
      IABIAS = -256 - LAMIN + NANG
      DO 850 KZ = 1,2
      IABIAS = IABIAS + 256
C
C     FIND HITS FOR CLOSEST NEIGHBORS
C
      DO 850 K = 1,NRIV
      KI = NBR(NBRI+K)
      IF(KI .EQ. 0) GO TO 850
      IK = KI+KI-1+IJ
      PX = PA(IK) + DPX
```

```
      PY = PA(IK+1) + DPY
      IANG = PAA(KI) + IABIAS
      DO 845 JK=1,8,2
      JSP = 8*(KI-1) + JK
      J = IAND(HIT(JSP),377K)
      IF(J.EQ. 9999) GO TO 850
      IF(J .EQ. JFM) GO TO 845
      J = (J-1)*3 + 1
      IEA = IABS(F(J+2) - IANG)
      IF(IEA .GT. ERAB) GO TO 845
      IEX = IABS(F(J) - PX)
      IF(IEX .GT. DDX) GO TO 845
      IEY = IABS(F(J+1) - PY)
      IF(IEY .GT. DDX) GO TO 845
      IET = IEX+IEY+IEA/ASFN
      IF(IET .GT. IETPN) GO TO 845
      IH = 4*K - 3
      IF(NHIT(IH) .EQ. 0) GO TO 835
      IF(NHIT(IH+2) .NE. 0) GO TO 825
      IF(NHIT(IH+1) .LE. IET) GO TO 830
  820 NHIT(IH+2) = NHIT(IH)
      NHIT(IH+3) = NHIT(IH+1)
      GO TO 835
  825 IF(IET .GE. NHIT(IH+3)) GO TO 845
```

```
          IF(IET .LT. NHIT(IH+1)) GO TO 820
      830 IH = IH+2
      835 NHIT(IH) = J
          NHIT(IH+1) = IET
      845 CONTINUE
      850 CONTINUE
      852 CONTINUE
C
C         ELIMINATE DUPLICATE FILE MINUTIA, SELECT BEST NEIGHBOR PAIRING
C
          DO 870 I = 1,NB4,4
          IF(NHIT(I) .EQ. 0) GO TO 870
      855 IFM = NHIT(I)
          J = I
      858 J = J+4
          IF(J .GT. NB4) GO TO 868
          IF(NHIT(J) .EQ. 0) GO TO 858
          IF(NHIT(J) .EQ. IFM) GO TO 860
          IF(NHIT(J+2) .NE. IFM) GO TO 858          ; I1 = J2,J1 .NE. 0
          NHIT(J+2) = 0
          NHIT(J+3) = 0
          GO TO 858
      860 IF(NHIT(I+2) .NE. 0) GO TO 865
          IF(NHIT(J+2) .NE. 0) GO TO 864            ; I1 = J1
          IF(NHIT(I+1) .LT. NHIT(J+1)) GO TO 862    ;I1=J1, I2 = 0
          NHIT(I) = 0                               ; I1=J1, I2=0, J2=0
          NHIT(I+1) = 0                             ; I1=J1 I2=0 J2=0, SJ1 .LE. SI1
          GO TO 870
```

```
      862 NHIT(J) = 0
          NHIT(J+1) = 0
          GO TO 858
      864 NHIT(J) = NHIT(J+2)
          NHIT(J+1) = NHIT(J+3)
          NHIT(J+2) = 0
          NHIT(J+3) = 0
          GO TO 858
      865 IF(NHIT(J+2) .EQ. 0) GO TO 866           ; I1=J1,I2.NE.0
          IF(NHIT(I+1) .LE. NHIT(J+1)) GO TO 864   ; I1=J1,I2.NE.0,J2.NE.0
      866 NHIT(I) = NHIT(I+2)                      ; I1=J1,TS.NE.0/J2=0 .OR. J2 .NE. 0, SI1 .GT.
          NHIT(I+1) = NHIT(I+3)
          NHIT(I+2) = 0
          NHIT(I+3) = 0
          GO TO 855
      868 NHIT(I+2) = 0
          NHIT(I+3) = 0                            ; I1 SELECTED
      870 CONTINUE
```

```
C
C      FIND SCORE FOR NEIGHBORS BASED ON VARIANCE OF FIT
C
       MXI = 0
       MYI = 0
       MTI = 0
       MXIS = 0
       MYIS = 0
       MTIS = 0
       IABIAS = -LAMIN+NANG
       NMM = 0
       K = 0
       DO 880 I = 1,NB4,4
       K = K+1
       IF(NHIT(I) .EQ. 0) GO TO 880
       NMM = NMM + 1
       J = NHIT(I)
       KI = NBR(NBRI+K)
       IF(KI .EQ. 0) GO TO 880
       IK = KI +KI - 1 +IJ
       ID = PA(IK) + DPX - F(J)
       MXI = MXI + ID
```

```
         MXIS = MXIS+ID*ID
         ID = PA(IK+1) + DPY - F(J+1)
         MYI = MYI + ID
         MYIS = MYIS + ID*ID
         ID = PAA(KI) + IABIAS - F(J+2)
         IF(IABS(ID) .GT. 127) ID = ID + 256
         MTI = MTI+ID
         MTIS = MTIS + ID*ID
     880 CONTINUE
         JSX = NMM - JSMIN + 1
         IF(JSX .GT. JSXMX) JSX = JSXMX
         IF(JSX .GE. 1) GO TO 885
         ITSX = 99
         ISCORV = 0
         ITSXS = 0
         GO TO 890
     885 IVX = ((MXIS - (MXI*MXI)/NMM)*IVARF)/NMM
         IVY = ((MYIS - (MYI*MYI)/NMM)*IVARF)/NMM
         IVT = ((MTIS - (MTI*MTI)/NMM)*IVARF)/(NMM*ASFS*ASFS)
         ITSX = (IVX+IVY+IVT)/3
         ITSX = ITSX - IVARMN
         IF(ITSX .GT. IVARMX) ITSX = IVARMX
         IF(ITSX .LT. 1) ITSX = 1
         IXJV = (JSX-1)*IVARMX+ITSX
```

```
      ISCORV = ISCTVR(IXJV)
  890 HIT(IS+1) = ISCORV
  895 CONTINUE
  898 CONTINUE
C
C     ORDER HIT ARRAY ENTRIES BASED ON SCORE
C
      DO 920 I = 1,NP8,8
      MX = -5
      MX2 = -10
      DO 910 J = 1,8,2
      IF(HIT(I+J) .EQ. 9999) GO TO 915
      IF(HIT(I+J) .LE. MX) GO TO 905
      MX2 = MX
      MX2N = MXN
      MX = HIT(J+I)
      MXN = HIT(J+I-1)
      GO TO 910
  905 IF(HIT(J+I) .LE. MX2) GO TO 910
      MX2 = HIT(J+I)
      MX2N = HIT(J+I-1)
  910 CONTINUE
  915 IF(MX .LT. 0) GO TO 920
      HIT(I) = MXN
      HIT(I+1) = MX
      IF(MX2 .LT. 0) GO TO 920
      HIT(I+2) = MX2N
      HIT(I+3) = MX2
```

```
      920 CONTINUE
C
C     SELECT LARGEST SCORE FROM HIT LIST MULTIPLE ENTRIES
C
          DO 960 I = 1,NP8,8
          IF(HIT(I) .EQ. 9999) GO TO 960
      925 IFM = IAND(HIT(I),377K)
          J = I
      930 J = J+8
          IF(J .GT. NP8) GO TO 960
          IF(HIT(J) .EQ. 9999) GO TO 930
          IF(IAND(HIT(J),377K) .EQ. IFM) GO TO 935     ; I .NE. 9999, J.NE. 9999
          IF(IAND(HIT(J+2),377K) .NE. IFM) GO TO 930   ; I1 .NE. J1
          HIT(J+2) = 9999                              ; I1 .NE. J1, J2 = I1
          HIT(J+3) = 9999
          GO TO 930
      935 IF(HIT(I+2) .NE. 9999) GO TO 948             ; I1 = J1
          IF(HIT(J+2) .NE. 9999) GO TO 945             ; I1 = J1,I2=9999
```

```
      IF(HIT(I+1) .GT. HIT(J+1)) GO TO 940           ; I1=J1,I2=9999,J2=9999
  937 HIT(I) = 9999
      HIT(I+1) = 9999
      GO TO 960
  940 HIT(J) = 9999                                   ; I1=J1,J2=9999,/I2=9999,SI1.GT.SJ1 .
      GO TO 930
  945 IF(HIT(J+1) .GE. HIT(I+1) + HIT(J+3)) GO TO 937 ; I1=J1,I2=9999,J2.NE.9999
  946 HIT(J) = HIT(J+2)                               ;I1=J1,J2.NE.9999,/I2=9999,SJ1.LT.SI1
      HIT(J+1) = HIT(J+3)                             ;    I2.NE.9999, SI1.GT.SJ1+SI2
      HIT(J+2) = 9999
      HIT(J+3) = 9999
      GO TO 930
  948 IF(HIT(J+2) .EQ. 9999) GO TO 950                ; I1=J1,I2.NE.9999
      IF(HIT(I+1) .GT. HIT(J+1)+HIT(I+3)) GO TO 946   ;I1=J1,I2.NE.9999,J2.NE.9999
      GO TO 952                                       ; I1=J1,I2.NE.9999,J2.NE.9999,SJ1.LT.
  950 IF(HIT(I+1) .GT. HIT(J+1) + HIT(I+3)) GO TO 940 ; I1=J1,I2.NE.9999,J2=9999
  952 HIT(I) = HIT(I+2)                               ; I1=J1,I2.NE.9999,/J2=9999,SI1.LT.SJ
      HIT(I+1) = HIT(I+3)                             ;    J2.NE.9999, SI1.LT.SI2+SJ1
      HIT(I+2) = 9999
      HIT(I+3) = 9999
      GO TO 925
  960 CONTINUE
C
```

	ATTRIBUTES	POSITION	SIZE
-- ARRAY --			
F	INTEGER ARRAY	0	612.
COUNT	INTEGER ARRAY	1144	2500.
SS	INTEGER ARRAY	1144	20.
NHIT	INTEGER ARRAY	2331	204.
HIT	INTEGER ARRAY	2521	204.
SCORET	INTEGER ARRAY	6050	160.
IXMIN	INTEGER	6310	
IXMAX	INTEGER	6311	
IYMIN	INTEGER	6312	
IYMAX	INTEGER	6313	
-- PLOTAG --			
PA	INTEGER ARRAY	0	4080.
S	INTEGER ARRAY	0	20.
IJS	INTEGER	7760	
XOFS	INTEGER	7761	
YOFS	INTEGER	7762	
IPAAB	INTEGER	7763	
PAA	INTEGER ARRAY	7764	204.
AVX	INTEGER	10300	
AVY	INTEGER	10301	
-- ARGS --			
LATID	INTEGER ARRAY	0	7.
ISCDA	INTEGER ARRAY	7	24.
NP	INTEGER	37	
P	INTEGER ARRAY	40	612.
IFCDA	INTEGER ARRAY	1204	16.
NF	INTEGER	1224	
ISCOR	INTEGER	1225	
IFLAG	INTEGER	1226	
PCN	INTEGER ARRAY	1227	9.
-- MATGP --			

IPAR	INTEGER ARRAY	0	256.
IVARMN	INTEGER	212	
JSXMX	INTEGER	211	
IVARMX	INTEGER	210	
IVARF	INTEGER	207	
JSMIN	INTEGER	206	
ASFS	INTEGER	77	
ASFN	INTEGER	76	
ERAB	INTEGER	75	
ASFP	INTEGER	74	
IOFLAG	INTEGER	53	
DDX	INTEGER	45	
IETPN	INTEGER	44	
IETP	INTEGER	43	
NYMAX	INTEGER	42	
NXMAX	INTEGER	41	
DX	INTEGER	40	
DELX	INTEGER	37	
ERAM	INTEGER	36	
ERAA	INTEGER	35	
NAT	INTEGER	34	
MXNBL	INTEGER	33	
IEOT	INTEGER	31	

-- STATIC VARIABLES --

NBR	INTEGER ARRAY	0	2448.
SUMX	INTEGER	4620	
SUMY	INTEGER	4621	
SDIV	INTEGER ARRAY	4622	32.
CDIV	INTEGER ARRAY	4662	32.
NBRS	INTEGER ARRAY	4722	33.
RIV	INTEGER ARRAY	4763	23.
NPOS	INTEGER ARRAY	5012	5.
NMAX	INTEGER ARRAY	5017	5.
ISCTVR	INTEGER ARRAY	5050	500.
ISTAB	INTEGER ARRAY	5024	512.
XOF	INTEGER	6034	
YOF	INTEGER	6035	
DPX	INTEGER	6036	
DPY	INTEGER	6037	
PX	INTEGER	6040	
PY	INTEGER	6041	
PXS	INTEGER	6042	
PYS	INTEGER	6043	

```
DELTH      INTEGER          6044
PXLX       INTEGER          6045
PYLY       INTEGER          6046
I          INTEGER          6047
NP3        INTEGER          6050
NPCD       INTEGER          6051
NN         INTEGER          6052
L          INTEGER          6053
NRIVS      INTEGER          6054
J          INTEGER          6055
K          INTEGER          6056
IEND       INTEGER          6057
NRIV       INTEGER          6060
IT         INTEGER          6061
N          INTEGER          6062
JA         INTEGER          6063
JB         INTEGER          6064
KK         INTEGER          6065
NXT1       INTEGER          6066
NANGLE     INTEGER          6067
IBA        INTEGER          6070
NF3        INTEGER          6071
KST        INTEGER          6072
NY1        INTEGER          6073
MMAX       INTEGER          6074
JZ         INTEGER          6075
NP8        INTEGER          6076
IH         INTEGER          6077
JH         INTEGER          6100
LH         INTEGER          6101
LH1        INTEGER          6102
LL         INTEGER          6103
NB4        INTEGER          6104
KZ         INTEGER          6105
JK         INTEGER          6106
IS         INTEGER          6107
NPK        INTEGER          6110
IER        INTEGER          6111
IRA        INTEGER          6112
NPT        INTEGER          6113
IDX        INTEGER          6114
IDY        INTEGER          6115
IR         INTEGER          6116
ITMP       INTEGER          6117
NP2        INTEGER          6120
NP2CD      INTEGER          6121
```

KM	INTEGER	6122
KKX	INTEGER	6123
JF	INTEGER	6124
LAMIN	INTEGER	6125
VX	INTEGER	6126
VY	INTEGER	6127
ICXF	INTEGER	6130
ICYF	INTEGER	6131
JFXMIN	INTEGER	6132
JFYMIN	INTEGER	6133
VX1	INTEGER	6134
LX	INTEGER	6135
LY	INTEGER	6136
IANS	INTEGER	6137
II	INTEGER	6140
IANGM	INTEGER	6141
NJ	INTEGER	6142
IABIAS	INTEGER	6143
IJ	INTEGER	6144
IANG	INTEGER	6145
NSS	INTEGER	6146
ISCORS	INTEGER	6147
IV	INTEGER	6150
JV	INTEGER	6151
NMAZ	INTEGER	6152
NANG	INTEGER	6153
IEA	INTEGER	6154
IEX	INTEGER	6155
IEY	INTEGER	6156
IET	INTEGER	6157
IT1	INTEGER	6160
IT2	INTEGER	6161
NBRI	INTEGER	6162
JFM	INTEGER	6163
JJ	INTEGER	6164
KI	INTEGER	6165
IK	INTEGER	6166
JSP	INTEGER	6167
IFM	INTEGER	6170
MXI	INTEGER	6171
MYI	INTEGER	6172
MTI	INTEGER	6173
MXIS	INTEGER	6174
MYIS	INTEGER	6175
MTIS	INTEGER	6176
NMM	INTEGER	6177

```
ID        INTEGER        6200
JSX       INTEGER        6201
ITSX      INTEGER        6202
ISCORV    INTEGER        6203
ITSXS     INTEGER        6204
IVX       INTEGER        6205
IVY       INTEGER        6206
IVT       INTEGER        6207
IXJV      INTEGER        6210
MX        INTEGER        6211
MX2       INTEGER        6212
MX2N      INTEGER        6213
MXN       INTEGER        6214
IPSINC    INTEGER        6215

-- EXTERNAL SUBPROGRAMS --

.ONCE      .OPSH      .DATI      .IERR      .ILEN
.IPEC      .IATT      .FOPE      PDBLK      .FCLO
.ITYP      .FWRS      .TTYP      ASORT      MINO
```

IDENTIFIER	REFERENCES												
ASFN	18	26	355										
ASFP	18	26	285										
ASFS	18	26	451										
ASUMT	57												
AVX	18	9	68	74									
AVY	18	9	69	75									
CDIV	18	31	134	135									
COUNT	18	8	26	179	208	209	211	212	222	223			
DDX	18	26	352	354									
DELTH	18	35	56	141	183	188	260						
DELX	18	26	155	157	161	162	166	167	207	255	256		
DPX	18	325	340	431									
DPY	18	326	341	434									
DX	18	26	282	284									
EHAA	18	26	56	204									
EHAB	18	26	350										
ERAM	18	26	280										
F	18	8	204	205	206	207	214	279	281	283	303	325	326
	349	351	353	431	434	437							
HIT	18	26	258	288	289	290	293	294	295	296	297	298	299
	318	319	320	345	458	468	469	472	473	475	476	477	480
	481	483	484	490	491	495	496	497	498	499	501	502	503
	504	505	507	508	510	511	512	513	514	516	517	519	520
	521	522	523	531	532								

I	65	66	57	73	74	75	76	83	87	88	117	143	145	178
		179	195	201	217	221	222	223	228	233	235	257	258	264
		265	266	272	306	375	376	377	378	387	389	390	391	402
		403	404	405	406	408	409	410	423	425	427	441	460	469
		469	472	473	475	476	477	480	481	483	484	485	489	490
		491	492	501	503	504	505	510	517	519	520	521	522	524
		525	530	531	532	536								
IABIAS	191	193	201	261	263	272	330	332	342	420	437			
IANG	201	204	214	272	279	303	342	349						
IANGM	183	188	191											
IANS	180	224	225	227	242									
IBA	192	217	262	306										
ICXF	159	161	197											
ICYF	160	162	198											
ID	431	432	433	434	435	436	437	438	439	440				
ID1	6													
ID3	6													
ID4	6													
ID5	6													
ID6	6													

IDX	90	92												
IDY	91	92												
IEA	279	280	285	349	350	355								
IEND	103	105	110	112	113									
IEUT	26	242												
IER	44													
IET	285	286	288	289	355	356	360	364	365	368				
IETP	26	286												
IETPN	24	356												
IEX	281	282	285	351	352	355								
IEY	283	284	285	353	354	355								
IFCOA	18	10												
IFLAG	10	39	146											
IFM	377	382	383	491	496	497								
IH	265	288	289	290	293	294	295	296	297	298	299	357	358	359
		360	361	362	364	365	366	367	368					
II	182	190	194											
IJ	194	196	197	198	254	246	321	339	430					
IJS	9													
IK	339	340	341	430	431	434								
IN	247	248	251	255										
IOFLAG	26													
IPAAB	9													
IPAR	18	11	26	93										
IPSINC	533	534												
IR	92	93	94	96	100									
IR4	54	57												
IS	317	318	319	320	458									

ISCDA	18	10							
ISCOR	18	10	48	529	533	535	537	538	541
ISCORS	241	537	538	541					
ISCORV	446	457	458	532	534	535			
ISCTVR	18	26	457						
ISTAB	18	26	44						
IT	82	115	116						
IT1	294	298							
IT2	295	299							
ITMP	104	107	109	111					
ITSX	445	452	453	454	455	456			
IT3XS	447								
IVARF	26	449	450	451					
IVLMMN	26	453							
IVARMX	26	454	456						
IVT	451	452							
IVX	449	452							
IVY	450	452							

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JV        456  457
MAX       8    155  159
MIN       8    155  159
MAX       8    157  160
MIN       8    157  160
          89   90   91   101  102  203  204  205  206  207  214  215  216  278
               279  281  283  290  303  304  305  345  346  347  348  349  351
               353  367  374  379  380  381  382  383  384  385  388  389  393
               394  396  397  398  399  401  402  427  431  434  437  467  468
               469  472  473  475  476  477  478  492  493  494  495  496  497
               498  499  502  503  507  508  510  511  512  513  514  516  517
               519
I         123  133
A         124  133  136
F         139  140  141  145
FM        319  347
FXMIN     161  255
FYMIN     162  256
H         287  288  289  290  291  292  293  294  295  296  297  298  299
J         320  325  326
K         343  344  369
N         248  249  250  256
SMIN      26   442
SP        344  345
SX        442  443  444  456
SXMX      26   443
Z         245  247  248  253  539
          95   96   97   98   99   100  101  142  144  145  266  270  271  336
```

		337	357	370	422	424	428							
:I	337	338	339	342	344	428	429	430	437					
(K	132	134	135	136	138	321	325	326						
(KX	139													
(M	125	127	132											
(ST	207	208	209	210	211	212								
(Z	331	370												
L	84	85	86	105	106	107	108	109	110	114	116	126	128	130
		137												
LAMIN	141	191	261	330	420									
LATIO	18	10												
LL	328	329												
LM	314	317	321	460										
LMI	316	317	459											
LX	166	199	205											
LY	167	200	206											
MINO	155	157												
MAAX	181	226	228	229	231	232	233	234	243	~~339~~				

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MPT	57													
MTI	416	439	451											
MTIS	419	440	451											
MX	465	469	470	472	479	481								
MX2	466	470	475	476	482	484								
MX2N	471	477	483											
MXI	414	432	449											
MXIS	417	433	449											
MXN	471	473	480											
MXNBL	26	51												
MYI	415	435	450											
MYIS	418	436	450											
N	133	134	135	136	202	203	273	274	278					
NANG	260	261	330	420										
NANGLE	187	229	234	236										
NAT	26	36	38	56	123	124	141	187	236					
NB4	169	328	329	375	380	410	423	441						
NBR	18	116	337	428										
NBRI	313	315	337	428										
NBRS	18	85	98	101	106	107	108	109	116					
NF	18	10	151											
NF3	151	203	216	274	278	305								
NHIT	18	26	329	358	359	360	361	362	364	365	367	368	376	377
		381	382	383	384	385	387	388	389	390	391	393	394	396
		397	398	399	401	402	403	404	405	406	408	409	425	427
NJ	189	202	215	259	273	304	327							
NMAX	18	229	234	253										
NMAZ	253	254	260											

NMM	421	426	442	449	450	451								
NY	81	83	89	102	117									
NP	18	10	37	52	57	61	68	69	81	121	143	145	168	195
		217	264	306	314	460								
NP2	121	122												
NP2CD	122	136	182	190	254									
NP3	61	62	65	67										
NPA	168	257	258	444	485	489	494	525	530	536				
NPCD	62	73	75	126	137									
NPK	37	38												
NPOS	18	228	233	247	249									
NRIV	51	52	80	103	114	116	169	313	315	336	370			
NRIVS	40	44	86	95	99	99								
NSS	222	224	225	227										
NX	155	156	161	163	166									
NX1	163	165												
NXMAX	26	155												
NXT1	165	178	179	221	235									

NY	157	158	162	164	167	250								
NY1	164	165	207	209	212	247	248							
NYMAX	26	157												
P	18	10	57											
PA	18	9	26	134	135	197	198	270	271	325	326	340	341	431
		434												
PAA	18	9	145	201	272	342	437							
PCN	18	10												
PX	18	87	90	128	129	134	197	199	205	270	281	340	351	
PXLX	18	199	207											
PXS	18	129	134	135										
PY	18	88	91	130	131	135	198	200	206	271	283	341	353	
PYLY	18	200	207											
PYS	18	131	134	135										
ROHLX	44													
RIV	18	86	94	96	97	100								
S	18	26	65	67	74	75	76							
SCORET	18	8												
SDIV	18	29	134	135										
SS	18	26	74	75	76	87	88	90	91	128	130	139	145	
SUMX	18	63	65	68										
SUMY	18	64	67	69										
XOF	18	255	270											
XOFS	18	9												
YOF	18	256	271											
YOFS	18	9												

122	257	258				
15	65	67				
25	73	75				
260	204	214				
275	203	205	206	213	216	
2783	291	300				
2786	288	292	293	301		
279	280	303				
280	278	242	284	286	302	305
290	262	264	303	306		
292	274	307				
3	178	179				
30	126	137				
300	192	195	214	217		
380	84	86				
399	225	231				
40	133	134				
400	221	224	230	235		
500	187	236				

108

601	249	252						
620	95	98						
65	39	147						
650	96	100						
750	89	93	94	102				
760	104	113						
770	105	106	110					
780	114	116						
799	111	114						
800	83	117						
8030	43	46	50					
810	328	329						
820	361	365						
825	359	364						
830	360	366						
835	358	363	367					
845	343	347	350	352	354	356	364	369
850	331	336	338	346	370			
855	377	407						
858	379	381	383	386	395	400		
860	382	387						
862	389	393						
864	388	396	402					
865	387	401						
866	401	403						
868	380	408						
870	375	376	392	410				
880	423	425	429	441				
885	444	449						
890	448	458						
695	316	459						
698	314	318	460					
90	143	145						
905	469	475						
910	467	474	475	478				
915	468	479						
920	464	479	482	485				
925	491	524						
930	493	495	497	500	509	515		
935	496	501						
937	504	510						
940	503	507	519					
945	502	510						
946	511	517						
948	501	516						
950	516	519						

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52        518   520
50        489   490   494   506   525
70        530   531   536
30        243   537   539
42        242   540

RGS       10
RRAY      H
ATGP      11
VMAT      0     360   377   535   719   1669 1695 1228
LOTAG     4
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APPENDIX II

NAME	PROGRAM VARIABLES - DESCRIPTION
ASFP	Θ Scale Factor for Minutia Pairing Distance
COUNT(2500)	Registration X, Y Histogram
DELTH	Δ angle between rotations in Units of 1.40625 degrees each
DDX	Minutia X, Y tolerance values for neighborhood scoring
DELX	Minutia X, Y cell size for print registration
DX	Tolerance values for minutia pairing
DPX	X offset to eactly overlay a registered search minutia with its mating file minutia
DPY	Y offset to exactly overlay a registered search minutia with its mating file minutia
ERAA	Minutia Angle tolerance for print registration
ERAB	Minutia Angle tolerance for neighboring pairing
ERAM	Minutia angle tolerance for minutia pairing
F(612)	Sorted file minutia X, Y Θ values
HIT(1632)	Array of mating file and search minutia
IFLAG	Switch, if = 1, then search data is ready
IXMAX	Maximum X value of file minutia set
IXMIN	Minimum X value of file minutia set
IYMAX	Maximum Y value of file minutia set
IYMIN	Minimum Y value of file minutia set
ICXF	X Coordinate of minutia pattern center for file minutia set
ICYF	Y Coordinate of minutia pattern center for file minutia set
IANS	Maximum value of registration histogram
ISCORS	Match score for a given registration histogram maximum
ISCOR	Final match score (maximum of ISCORS values)

APPENDIX II (CONTINUED)

NAME	PROGRAM VARIABLES - DESCRIPTION
ASFP	Θ [illegible] Factor for Minutia Pairing Distance
COUNT(2500)	F [illegible]tion X, Y Histogram
DELTH	[illegible]e between rotations in Units of 1.40625 degrees each
DOX	Minu[illegible] X, Y tolerance values for neighborhood scoring
DX	Minutia X, Y cell size for print registration, tolernace values for minutia pairing
DPX	X offset to exactly overlay a registered search minutia with its mating file minutia
DPY	Y offset to exactly overlay a registered search minutia with its mating file minutia
ERAA	Minutia Angle tolerance for print registration
ERAB	Minutia Angle Tolerance for Neighboring Pairing
ERAM	Minutia angle tolerance for minutia pairing
F(612)	Sorted file minutia X, Y Θ values
HIT(1632)	Array of mating file and search minutia
IFLAG	Switch, if = 1, their search data is ready
IXMAX	Maximum X values file minutia set
IXMIN	Minimum X values file minutia set
IYMAX	Maximum Y values file minutia set
IYMIN	Minimum Y values file minutia set
ICXF	X Coordinate of minutia pattern center for file minutia set
ICYF	Y Coordinate of minutia pattern center for file minutia set
IANS	Maximum value of registration histogram
ISCORS	Match score for a given registration histogram maximum
ISCOR	Find match score (maximum of ISCORS values)

APPENDIX II (CONTINUED)

NAME	PROGRAM VARIABLES - DESCRIPTION
ISTAB	Array Containing Score Table
IJ	Pointer to PA array for best set of rotated search minutia
*IEOT	Early out threshold
IETP	Distance Tolerance for minutia pairing
ITSX	Scaled Variance of Matching Neighboring Minutia
ISCTVR(500)	Score Table
ISCORV	Individual Minutia Score
JXMIN	X Coordinate of Lower Left Corner of File Minutia Pattern
JYMIN	Y Coordinate of Lower Left Corner of File Minutia Pattern
JSCOR	Number of matching neighbors for a particular search minutia
KF(700)	Array of file minutia that are mated with search minutia
LX	1/2 width of effective file minutia pattern area
LY	1/2 height of effective file minutia pattern area
LAMIN	Maximum angle bias for search minutia angles
MHIT(48)	Array of file minutia mating with neighbors of a given search minutia
MMAX	Number of maximums in registration histograms
NB4	Number of neighbors to use times 4
NF	Number of file minutia
NMAX(5)	Array of best rotation for registration
NAT	Number of search print rotations to use
NF3	3 Times the number of file minutia
NRIV	Number of neighbors to use for neighborhood scoring
NP	Number of search minutia

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[illegible]IX II (CONTINUED)

NAME	PRO[illegible] [illegible]ARIABLES - DESCRIPTION
NBR(2040)	Neighbor array
NX	Count array size in X (number of cells to use in count array in X direction)
NMN	Number of matching neighbors
NY	Count array size in Y (number of cells to use in count array in Y direction)
NP8	Number of search minutia times 8
NXMAX	Maximum number of count array cells in X direction
NYMIN	Maximum number of count array cells in Y direction
P(612)	Unsorted search minutia
PA(2040)	Rotated search minutia X, Y values
PAA(204)	Search minutia angle values
R40STB	Disk file containing score table
S(612)	Sorted Search Minutia
SS(612)	Sorted, Centered, Search Minutia
XOF	X offset to overlay search minutia on file minutia for registration histogram maximum
YOF	Y offset to overlay search minutia on file minutia for registration histogram maximum

1. A method employing a programmed computer for comparing the minutiae of a search fingerprint (the "search minutiae") with the minutiae of a file fingerprint (the "file minutiae") to determine if the search fingerprint closely resembles the file fingerprint comprising:
   - (a) rotating and translating the search minutiae to determine the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae;
   - (b) pairing mating search and file minutiae;
   - (c) computing an individual minutia score for each search minutia that has a mating file minutia based on the spatial and angular relationship between the other mating file and search minutiae located within a neighborhood of each such search minutia; and
   - (d) summing the individual minutia scores to obtain a final match score indicative of the overall resemblance of the search fingerprint to the file fingerprint.

2. The method described in Claim 1 and further comprising:
   - (a) sorting the search minutiae into angle order;
   - (b) finding the closest neighbors for each search minutia;
   - (c) sorting the file minutiae into angle order; and
   - (d) computing maximum and minimum coordinates for the file minutia.

3. The method described in Claim 1 or 2 and further comprising terminating the comparison between the minutiae of a search fingerprint and the minutiae of a file fingerprint whenever the degree of registration of the search minutiae with the file minutiae fails to exceed an operator selected threshold.

4. A method employing a programmed computer for comparing the minutiae of a search fingerprint (the "search minutiae") with the minutiae of a file fingerprint (the "file minutiae") to determine if the searc[illegible] fingerprint closely resembles the file fingerprint comprising the [illegible] steps in the order named:

   [illegible]tating and translating the search minutiae to determine [illegible]rotation and translation which most nearly brings [illegible]rch minutiae into registration with the file mi[illegible].

   (b) pairi[illegible] mating search and file minutiae;

   (c) computing an individual minutia score for each search minutia that has a mating file minutia based on the spatial and angular relationship between the other mating file and search minutiae located within a neighborhood of each search minutia; and

   (d) summing the individual minutia scores to obtain a final match score indicative of the overall resemblance of the search fingerprint to the file fingerprint.

5. The method described in Claim 4 and further comprising the following steps in the order named, and performed prior to the first step described in Claim 1:

   (a) sorting the search minutiae into angle order;

   (b) finding the closest neighbors for each search minutia;

   (c) sorting the file minutiae into angle order; and

   (d) computing maximum and minimum coordinates for the file minutia.

6. The method described in Claim 4 and further comprising the following step performed between steps (b) and (c) of Claim 4: terminating the comparison between the minutiae of a search fingerprint and the minutiae of a file fingerprint whenever the degree of registration of the search minutiae with the file minutiae fails to exceed an operator selected threshold.

7. The method described in Claim 5 or 6 wherein the step of rotating and translating the search minutiae to determine the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae comprises:
   (a) rotating the search minutiae through a preselected set of rotations;
   (b) for each rotated set of search minutia constructing a histogram showing the number of coincident search and file minutiae for various translations of the search minutiae relative to the file minutiae; and
   (c) determining the rotation and translation to which most nearly brings the search minutia into registration with the file minutiae by comparing the magnitudes of the largest adjacent blocks of entires in each of the histograms.

8. A device for comparing the minutiae of a search fingerprint (the "search minutiae") with the minutiae of a file fingerprint (the "file minutiae") to determine if the search fingerprint closely resembles the file fingerprint comprising:
   (a) rotating and translating means for rotating and translating the search minutiae to determine the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae;
   (b) pairing means for pairing mating rotated and translated search and file minutiae;
   (c) scoring means for computing an individual minutia score for each search minutia that has a mating file minutia based on the spatial and angular relationship between the other mating file and search minutiae located within a neighborhood of each such search minutia; and
   (d) summing means for summing the individual minutia scores to obtain a final match score indicative of the overall resemblance of the search fingerprint to the file fingerprint.

9. The device described in Claim 8 and further comprising:
   (a) first sorting means for sorting the search minutiae into angle order;
   (b) finding means for finding the closest neighbors for each search minutia;
   (c) second sorting means for sorting the file minutiae into angle order; and
   (d) coordinate means for computing maximum and minimum coordinates for the file minutia.

10. The device described in Claim 8 or 9 and further comprising terminating means for terminating the comparison between the minutiae of a search fingerprint and the minutiae of a file fingerprint whenever the degree of registration of the search minutiae with the file minutiae fails to exceed an operator selected threshold.

11. The device described in Claim 8 or 9 wherein the rotating and translating means for rotating and translating the search minutiae to determine the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae comprises:
    (a) rotating means for rotating the search minutiae through a preselected set of rotations;
    (b) for each rotated set of search minutiae constructing means for constructing a histogram showing the number of coincident search and file minutiae for various translations of the search minutiae relative to the file minutiae; and
    (c) determining means for determining the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae by comparing the magnitudes of the largest adjacent blocks of entries in each of the histograms.

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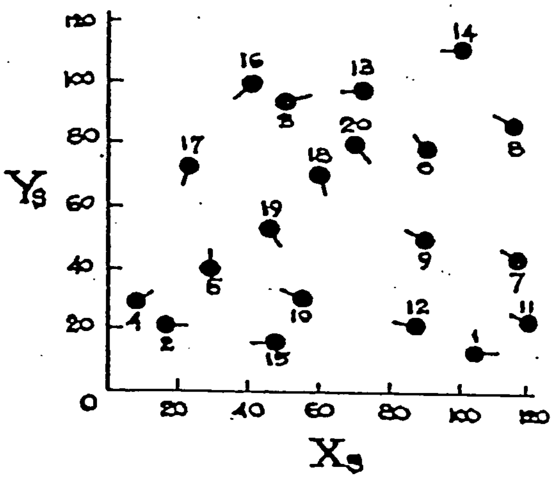
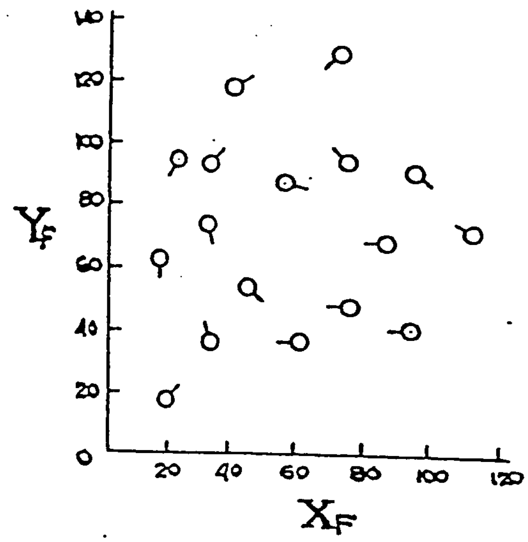


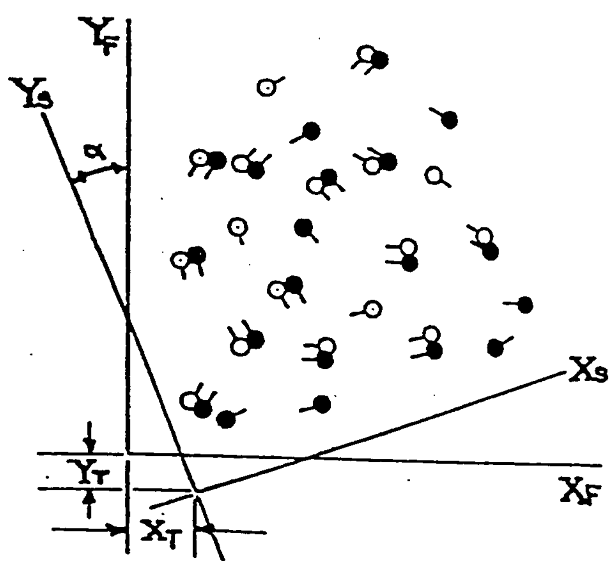
SEARCH MINUTIA

FIG. 1A



FILE MINUTIA

FIG. 1B



SEARCH MINUTIA SUPERIMPOSED ON FILE MINUTIA

FIG. 1C

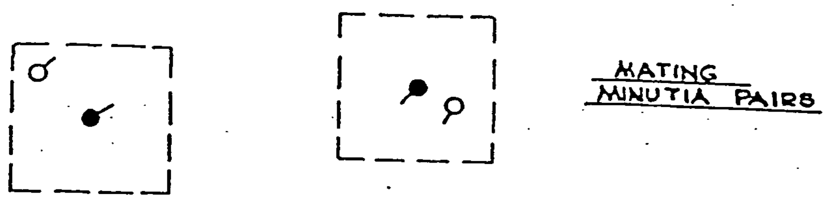


FIG. 2A

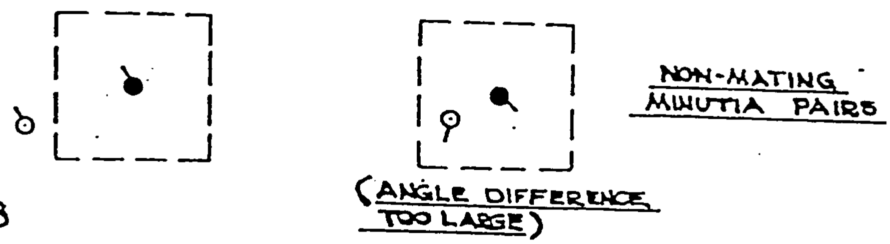


FIG. 2B

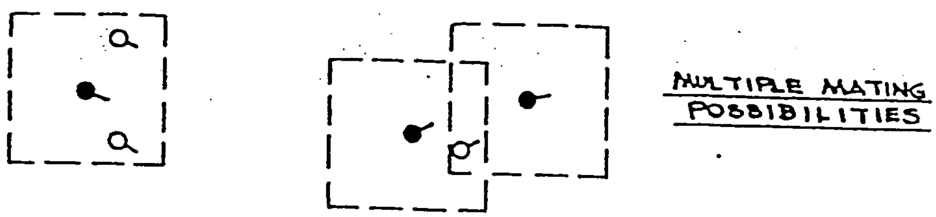


FIG. 2C

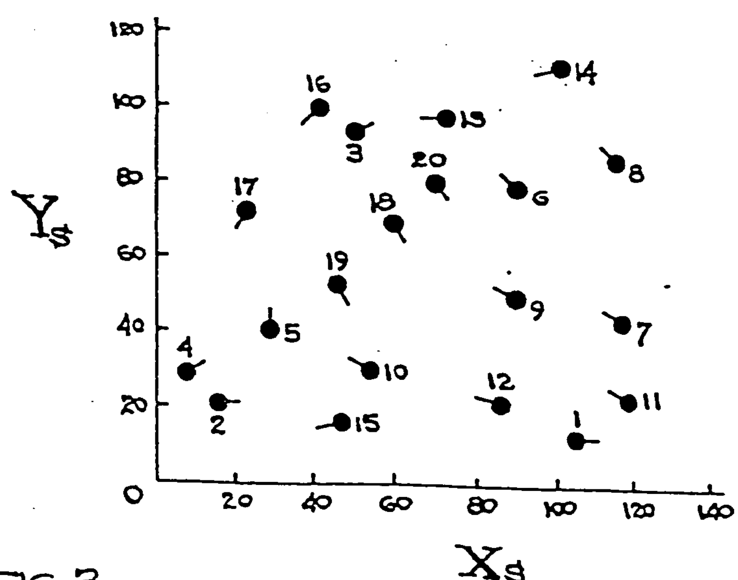
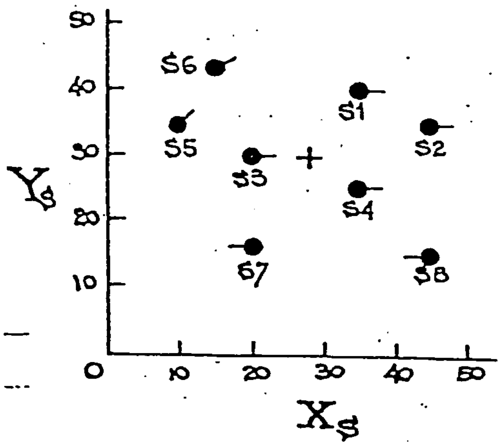


FIG. 3



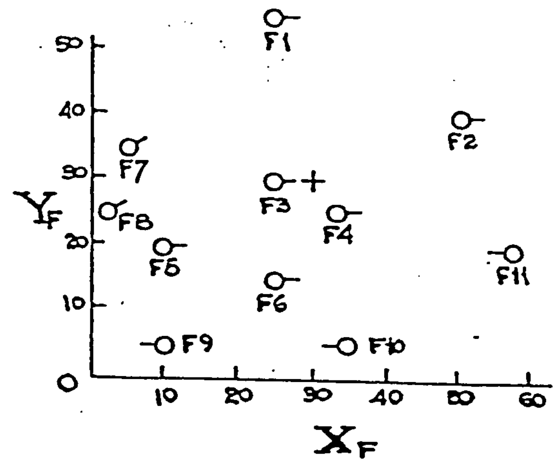
SEARCH MINUTIA PATTERN

TRANSLATION EQUATIONS:

$\Delta X = X_S - X_F + 2$

$\Delta Y = Y_S - Y_F$

FIG. 4A



FILE PRINT MINUTIA PATTERN

FIG. 4B

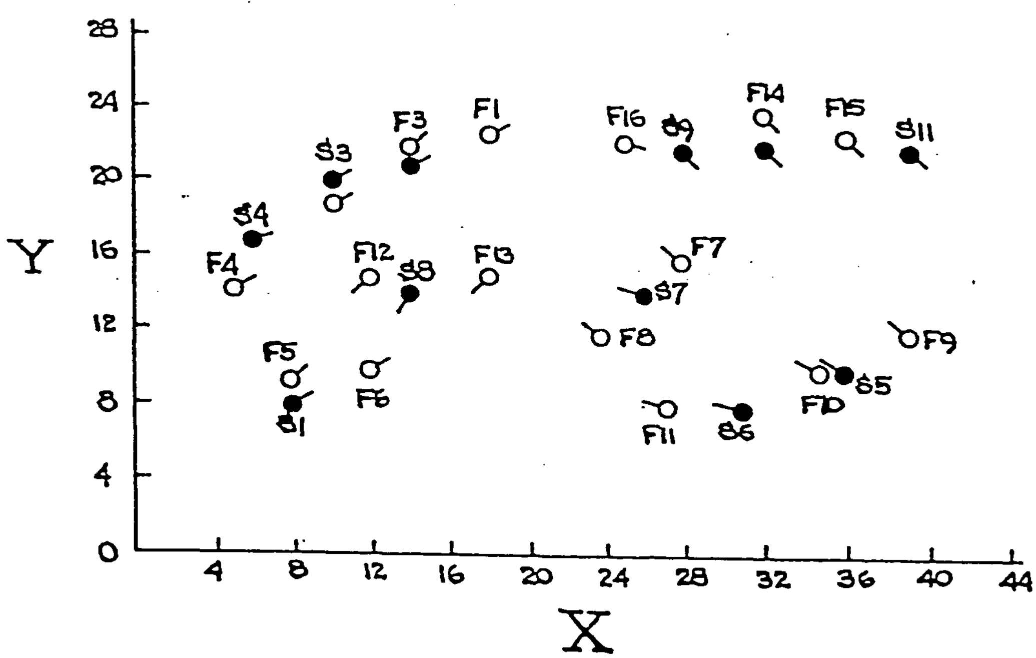


FIG. 7

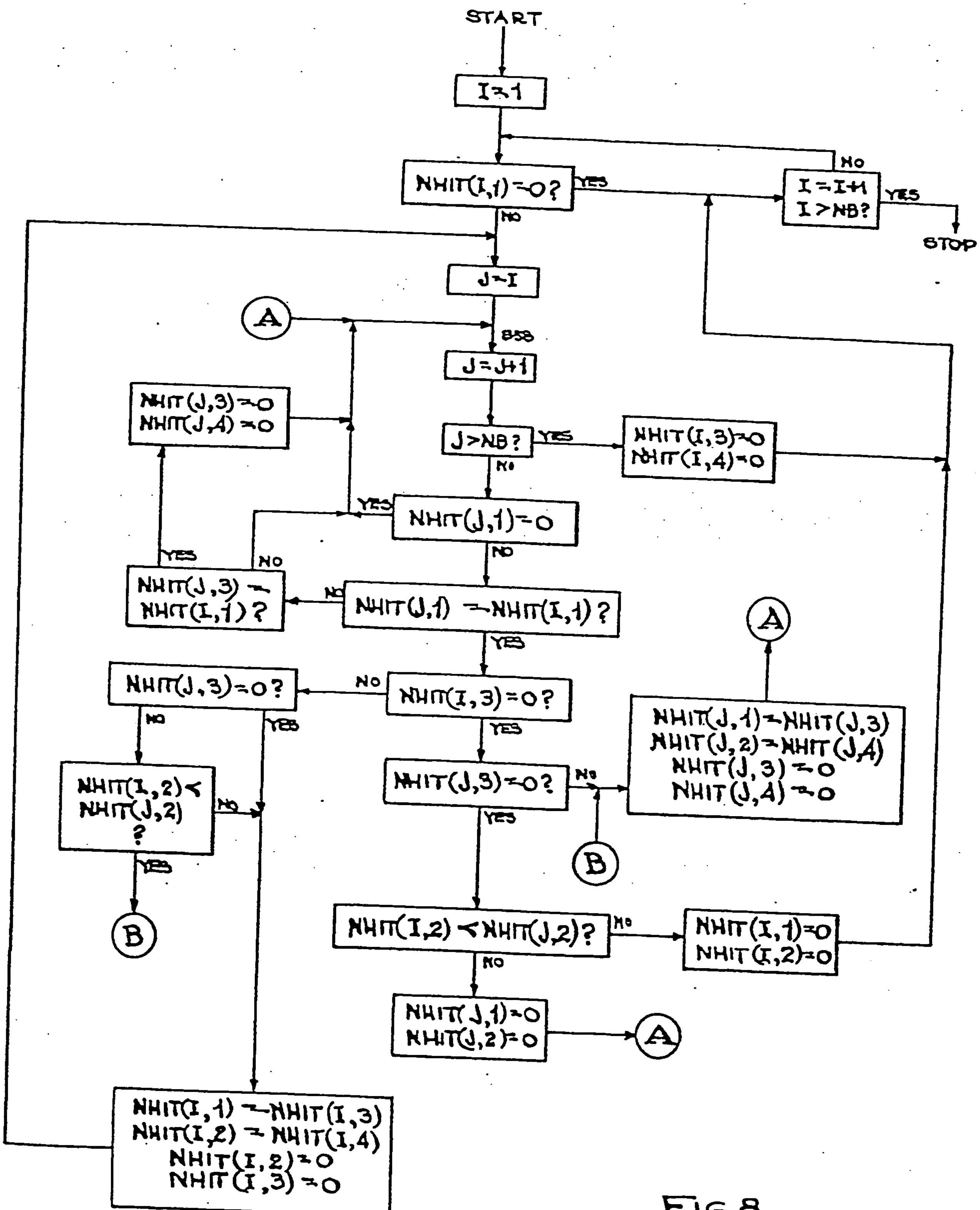
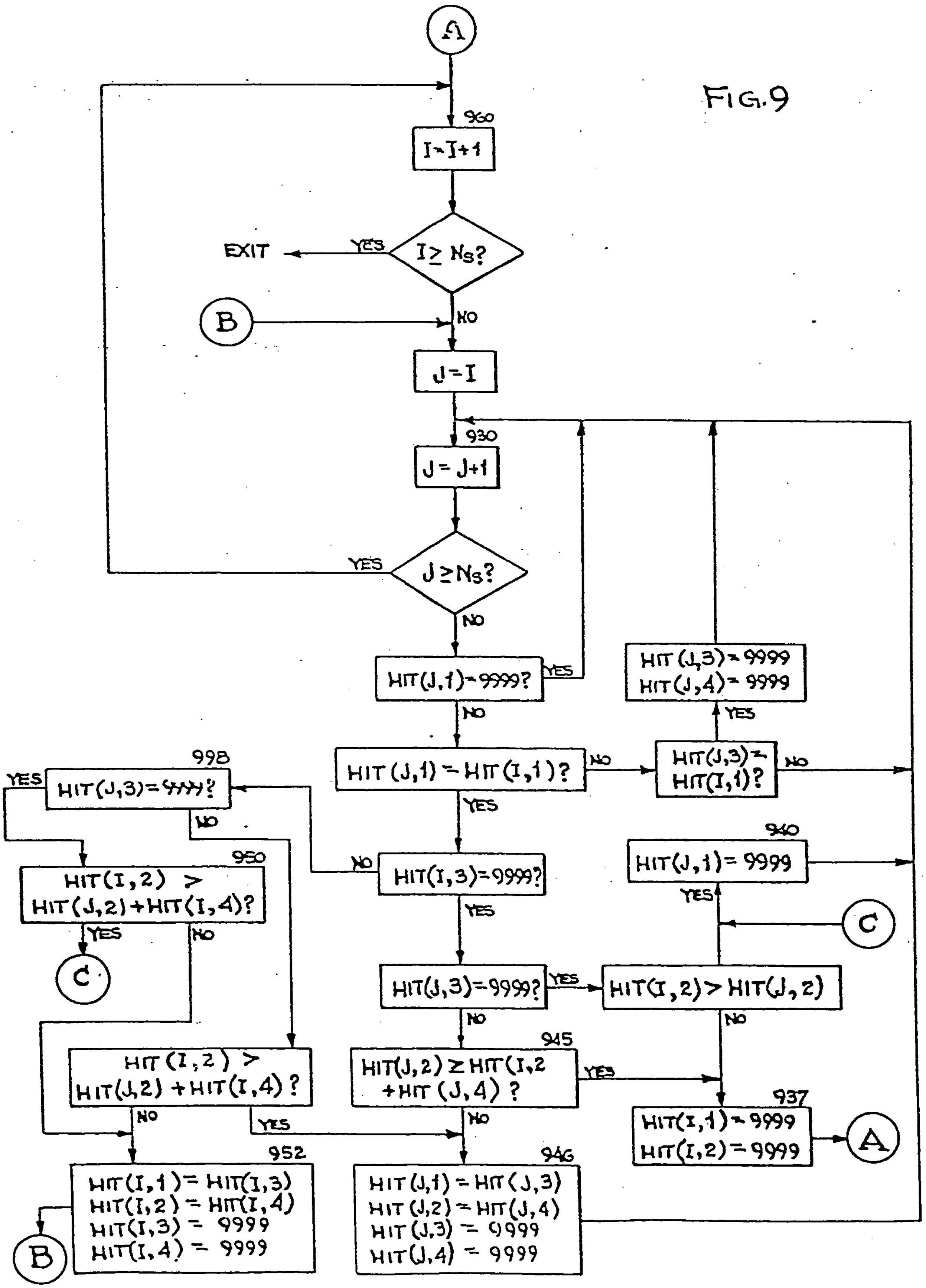

START
I=1
NHIT(I,1)=0?
YES
NO
I=I+1
I>NB?
YES
NO
STOP
J=I
A
858
J=J+1
NHIT(J,3)=0
NHIT(J,4)=0
J>NB?
YES
NO
NHIT(I,3)=0
NHIT(I,4)=0
NHIT(J,1)=0
YES
NO
NHIT(J,3)=NHIT(I,1)?
YES
NO
NHIT(J,1)=NHIT(I,1)?
NO
YES
NHIT(J,3)=0?
NO
YES
NHIT(I,3)=0?
NO
YES
NHIT(J,1)=NHIT(J,3)
NHIT(J,2)=NHIT(J,4)
NHIT(J,3)=0
NHIT(J,4)=0
NHIT(I,2)<NHIT(J,2)?
NO
YES
B
NHIT(J,3)=0?
NO
YES
NHIT(I,2)<NHIT(J,2)?
NO
NHIT(I,1)=0
NHIT(I,2)=0
NHIT(J,1)=0
NHIT(J,2)=0
NHIT(I,1)=NHIT(I,3)
NHIT(I,2)=NHIT(I,4)
NHIT(I,2)=0
NHIT(I,3)=0

FIG.8

FIG. 9


A
960
I=I+1
I ≥ Ns?
YES
EXIT
NO
B
J=I
930
J=J+1
J ≥ Ns?
YES
NO
HIT(J,1)=9999?
YES
NO
HIT(J,1)=HIT(I,1)?
NO
YES
HIT(J,3)=HIT(I,1)?
NO
YES
HIT(J,3)=9999
HIT(J,4)=9999
998
HIT(J,3)=9999?
YES
NO
HIT(I,3)=9999?
NO
YES
940
HIT(J,1)=9999
YES
C
950
HIT(I,2) > HIT(J,2)+HIT(I,4)?
YES
NO
C
HIT(J,3)=9999?
YES
HIT(I,2)>HIT(J,2)
NO
945
HIT(J,2) ≥ HIT(I,2 +HIT(J,4)?
YES
NO
HIT(I,2) > HIT(J,2)+HIT(I,4)?
NO
YES
937
HIT(I,1)=9999
HIT(I,2)=9999
A
952
HIT(I,1)=HIT(I,3)
HIT(I,2)=HIT(I,4)
HIT(I,3)=9999
HIT(I,4)=9999
B
946
HIT(J,1)=HIT(J,3)
HIT(J,2)=HIT(J,4)
HIT(J,3)=9999
HIT(J,4)=9999